TECHNICAL REPORT
70-54-ES





# ENVIRONMENTAL GUIDE FOR ARCTIC TESTING ACTIVITIES AT FORT GREELY, ALASKA

by
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May 1971



Earth Sciences Laboratory
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13. ABSTRACT


The physical environment of the Fort Greely area is analyzed and evaluated with special reference given to the significance of climate, terrain, and vegetation on testing activities at the various courses and ranges of the test site. Cold spells under -25° and -40°F are studied for their frequency and duration of occurrence at the test areas. It is shown that there is considerable variation in minimum temperature within the area, with Bolio Lake, for example, often being 10 to 15 F° colder than the main weather station. Differences within one mile may be as great as 40 F° on some calm, clear winter nights. Even under these conditions, however, temperatures suitable for cold testing are not reached on very many nights, and a temperature of -70 F, the design temperature given in Army Regulation 70-38 for extreme cold, has never been attained. The chance of a minimum of -25 F, the uppermost temperature acceptable for cold tests, is only one in fifteen for any given date between 13 November and 18 March at the main station.

Visibility restrictions such as ice fog, blowing dust, and snow are occasionally present during the winter season. Solar and lunar illuminations are discussed and a table of the phases of the moon through 1980 is presented.

A comparison of the climate at Ft. Greely with other possible test locations in Alaska indicates that other locations are better temperaturewise, but possible difficulties associated with accessibility might make them impractical.

Methods for dealing with snow and ice are discussed. Procedures for taking meteorological observations and for determining snow properties are outlined, and the test facilities at Ft. Greely are described.


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## FOREWORD

This guide was written jointly by personnel at U. S. Army Natick Laboratories and U.S. Army Cold Regions Research and Engineering Laboratory to more completely and accurately portray the essential environmental characteristics of the Army's Arctic Test Center at Fort Greely, Alaska. The material in Section 5 and Appendices A and B was written by the staff of the U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, consisting of Mr. Fred J. Sanger, Project Supervisor, and Messrs. C. Abele, M. Bilello, M. Bates, G. Frankenstein, J. Hicks, W. Parrott, P. Sellman, and D. Smith, Technologists. The rest of the study was prepared by Dr. Richard Sands and Mr. Howard L. Ohman of the Earth Sciences Laboratory, U.S. Army Natick Laboratories.

Members of the U.S. Army Meteorological Team, Alaska, and the Instrumentation and Test Methodology Division of the Arctic Test Center at Fort Greely contributed data and information which were utilized in the preparation of the weather and climate chapters.

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## ABSTRACT

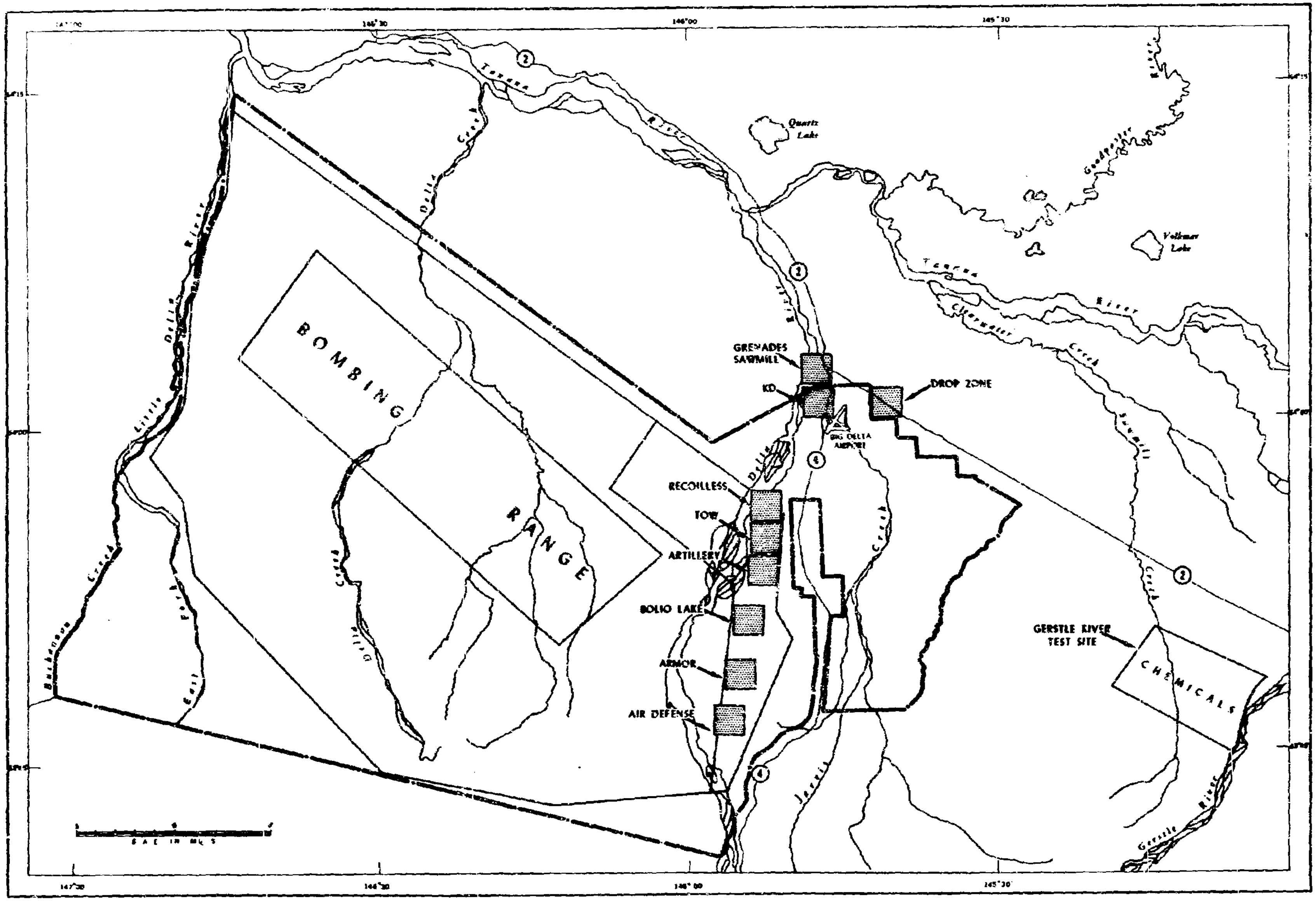
The physical environment of the Fort Greely area is analyzed and evaluated with special reference given to the significance of climate, terrain, and vegetation on testing activities at the various courses and ranges of the test site. Cold spells under -25° and -40°F are studied for their frequency and duration of occurrence at the test areas. It is shown that there is considerable variation in minimum temperatures within the area, with Bolio Lake, for example, often being 10 to 15 F° colder than the main weather station. Differences within one mile may be as great as 40 F° on some calm, clear winter nights. Even under these conditions, however, temperatures suitable for cold testing are not reached on very many nights, and a temperature of -70°F, the design temperature given in Army Regulation 70-38 for extreme cold, has never been attained. The chance of a minimum of -25°F, the uppermost temperature acceptable for cold tests, is only one in fifteen for any given date between 13 November and 18 March at the main station.

Visibility restrictions such as ice fog, blowing dust, and snow are occasionally present during the winter season. Solar and lunar alignment are discussed and a table of the phases of the moon through 1980 is presented.

A comparison of the climate at Fort Greely with other possible test locations in Alaska indicates that other locations are better temperaturewise, but possible difficulties associated with accessibility might make them impractical.

Methods for dealing with snow and ice are discussed. Procedures for taking meteorological observations and for determining snow properties are outlined, and the test facilities at Fort Greely are described.

HEADQUARTERS U.S. ARMY ARCTIC TEST CENTER FORT GREELY, ALASKA




Frontispiece

ENVIRONMENTAL GUIDE FOR ARCTIC TESTING ACTIVITIES AT FORT GREELY, ALASKA

# I. Introduction

## A. Climate

Short, cool summers and long, very cold winters identify the climate of Fort Greely as subarctic in type - a type common to much of the high latitude boreal zone of northern North America and northern Eurasia. Specific winter weather conditions needed to test equipment are not as characteristic of Fort Greely, however, as of other sites within the interior of Alaska. Although severe cold can and does occur on occasion, it is seldom as prolonged as the cold experienced farther from the Alaska Range. Relatively high temperatures sometimes occur when air moves from the Alaska Range through Isabel Pass and is heated adiabatically (by compression) before arriving at Fort Greely. Fairbanks, farther down-valley from Fort Greely and away from the influence of the adiabatically heated air, experiences from 25% to 152% more days suitable for testing, although not as many as Bolio Lake - a test site of the Arctic Test Center.* Possibly the most favorable cold-weather testing conditions occur somewhere in the lowlands of the upper Yukon between Circle and Fort Yukon, but a special study would have to be made to determine the most appropriate site. A slightly higher frequency of temperatures suitable for cold tests can be expected upvalley from Fort Greely at Northway where the Arctic Test Center sends equipment and personnel during times when conditions are not suitable at Fort Greely.

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* A suitable testing day is defined as a day when the minimum temperature reaches or exceeds -25°F. Bolio Lake, the coldest and most frequently used test site for low temperatures at Fort Greely, compares very favorably with Fairbanks and Fort Wainwright. Based upon analysis of the five winters from 1963-1968, Bolio Lake experiences 48% more days with -50°F min. and 27% more days with -40°F min. than Fairbanks. Fairbanks, however, experiences 3% more days when the minimum temperature is between -25°F and -40°F than does the Bolio Lake test site.

## B. Surface and Terrain Conditions

### 1. Terrain

The following terrain types are common to the Big Delta Test Area: Highlands (generally 2,500 feet and above); Lowland and Flat Surfaces (generally less than 1,500 feet); and Kame-Kettle Surfaces (low hills and lakes, 1,500 to 2,500 feet). The distribution of the types is shown on the terrain map, Figure 1, and their characteristics summarized in Table I. The surface and terrain features of the area are largely the result of glacial action, past and present. Many of the surface features are remnants of deposits left by glaciers that extended over this area in the past. With the passing of time, erosion and peat deposits altered the original surface formations considerably, with the present surface types finally emerging.

### 2. Surface Materials

Much of the surface material consists of layers of peat varying in depth from a few inches to many feet. Hundreds of small lakes and swampy lake beds dot large sections of the Test Area. Extensive sand bars and other alluvial materials characterize the flood plains, and large areas of broken rock fragments cover the steeper slopes and summits of the highlands and hills.

### 3. Drainage

The Test Area is bounded on the west by the Delta River and on the east by Jarvis Creek. Both streams have gentle gradients and braided channels. Many of the smaller tributary streams flow in narrow channels that are choked by thickets of willow and alder in many places. The flow in the streams is principally produced and controlled by snowmelt in the spring and the melting of glacier ice to the south later in the summer.

## C. Vegetation

### 1. General

The distribution of vegetation types is shown on Figure 2, and further information is given in Table II. Vegetation types vary with elevation and drainage and are particularly subject to alteration by forest fire. Where permafrost layers occur near the surface, drainage is poor and few species are able to exist. In areas that have been burned over there is a young vegetation cover of trees of small diameters and heights.

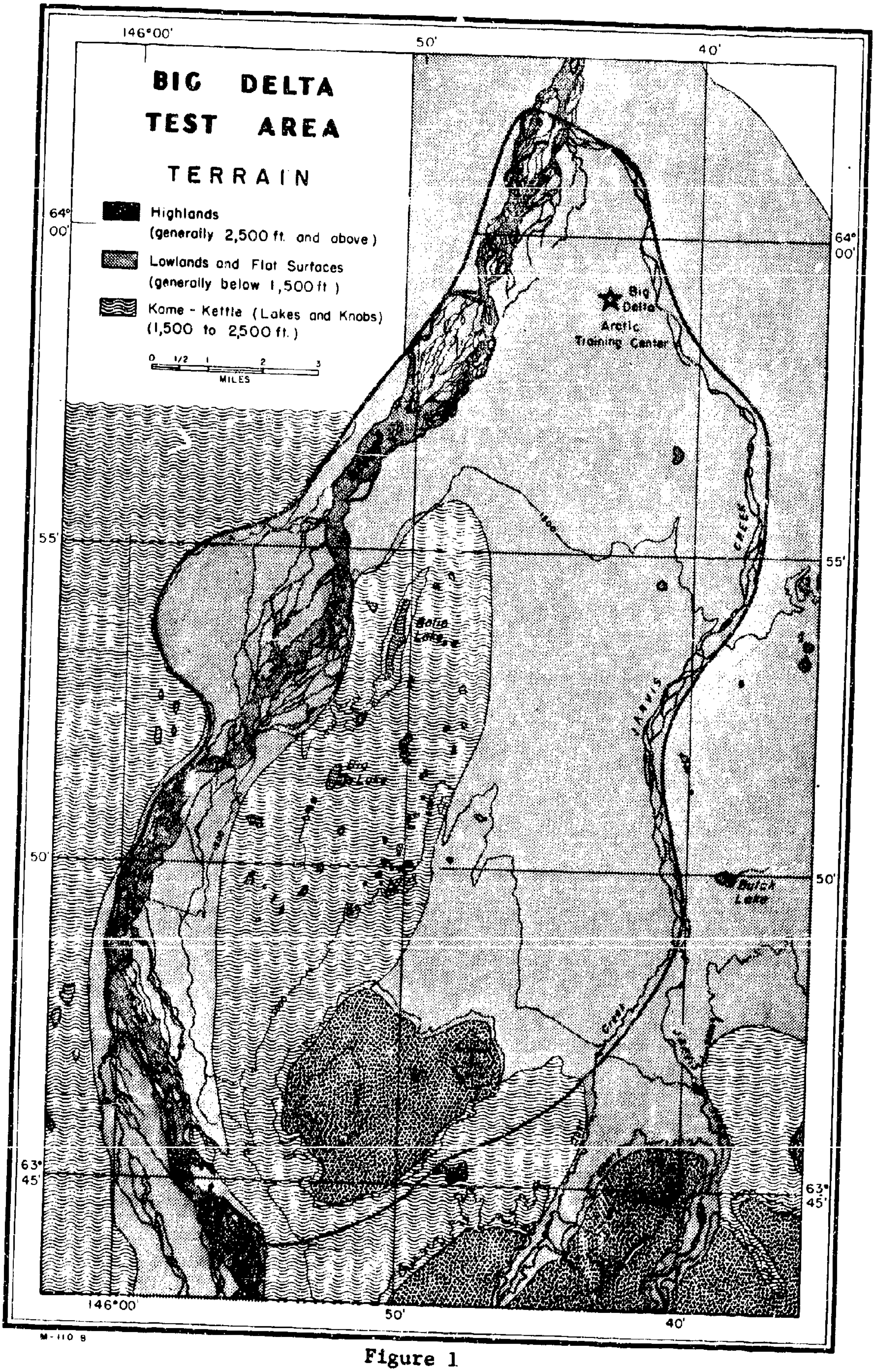

BIG DELTA
TEST AREA
TERRAIN
Highlands
(generally 2,500 ft. and above)
Lowlands and Flat Surfaces
(generally below 1,500 ft.)
Kame - Kettle (Lakes and Knobs)
(1,500 to 2,500 ft.)
0 1/2 1 2 3
MILES
146°00'
50'
40'
64° 00'
55'
50'
63° 45'
Big Delta
Arctic Training Center
Bolio Lake
Big Lake
Butch Lake
M-110 B

Figure 1

TABLE I. SUMMARY OF SURFACE AND TERRAIN FEATURES

IN THE FORT GREELY TEST AREA

| Terrain Type | Elevation & Average Slopes | Surface Material | Drainage | Vegetation | Remarks |
|---|---|---|---|---|---|
| HIGHLANDS | 2,500 feet and above- 20% to 40% | Granite and schist bedrock outcrops at higher elevations. Slopes covered with rock fragments. | Good all year | Tundra mosses and lichens, blueberry, cranberry, crowberry, mossberry, labrador tea, small sedges, willow and scattered birch. Spruce, usually black, and aspen on slopes and hilltops. | The only highland section within the Test Area is Donnelly Dome and the surrounding area. Rising to such slight elevation, the section affords little opportunity for mountain testing; mountain areas may be found in the Alaskan Range 40 to 50 miles south. |
| FLAT SURFACES | Below 1,500 feet- 2% to 8% | Flood plains have layers of silt and gravels. Layers of peat have formed over the glacier gravels of this section. | Flood plains are flat and often flooded in the spring. Gravel plains are better drained. General drainage improves southward. | Willow, alder, birch, aspen, and scattered spruce with thick undergrowth of sedge and heath. Also areas of swamp with sedges. Thick young stands of forest now dominate burned areas. | Flood plains within the test area are wide, flat, and braided. Spring and early summer flooding occurs along the valleys. Level plains away from rivers are better drained and have been burned over. |
| KAME-KETTLE (Knobs and Lakes) | 1,500 to 2,500 feet- 20% to 25% | Coarse glacial-deposited gravels covered by layers of peat. Old lake bottoms filled with thick layers of peat. Hilltops have gravel material at surface. | Poor in lowland areas; good at all seasons on steep slopes and hilltops. | Lowlands covered with swamp grasses and sedges in both tussock and meadow formations. On better drained slopes dwarf willow, alder, and heath show up. Hilltops often bare except for mosses and lichens. | Consists of moraine materials deposited by glacier. In the older deposit the sharp features have been eroded and lakes have been filled until they are meadow-like swamp areas. In more recent deposits lakes and steeper hills are present. Summer transportation is difficult. |

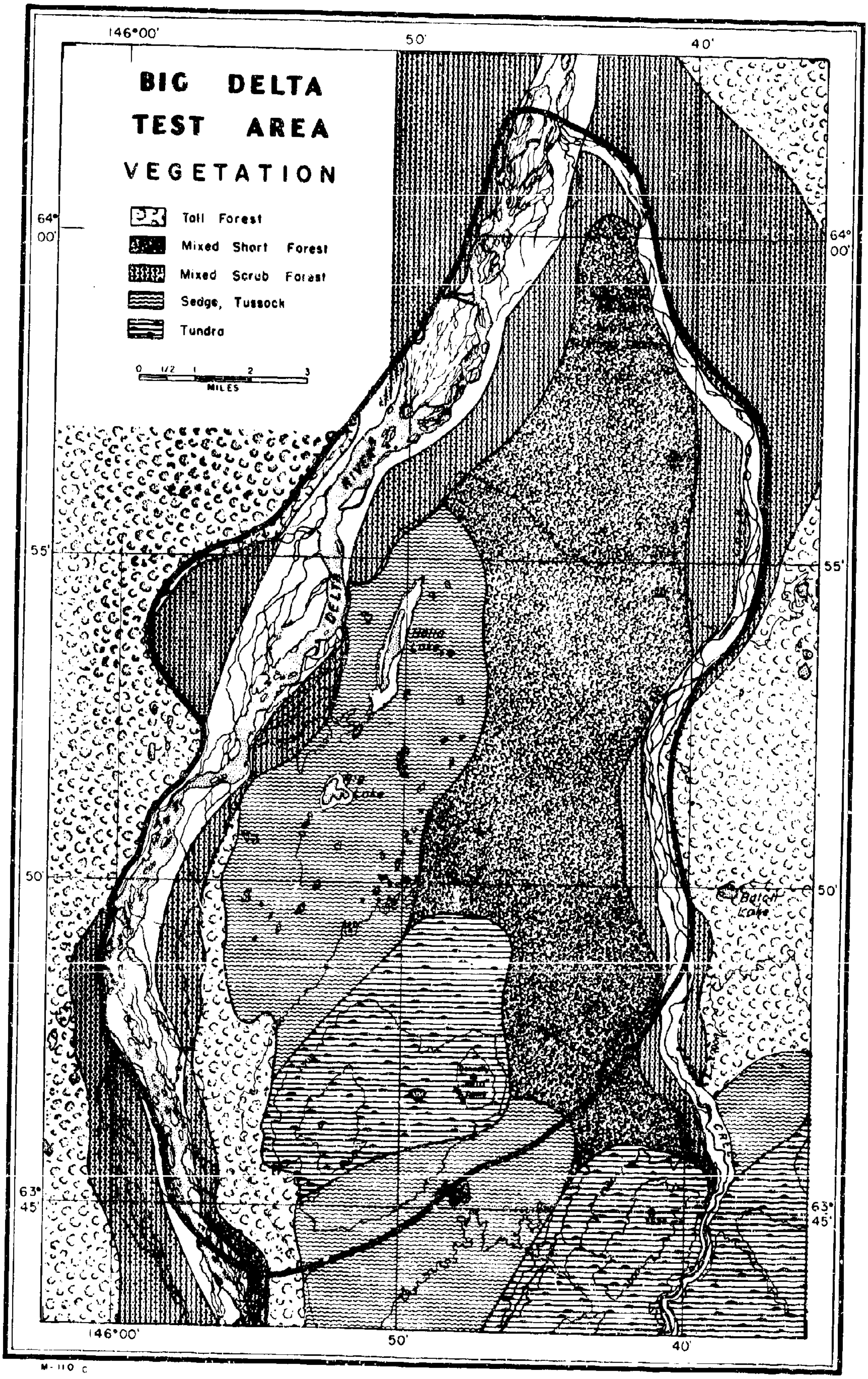

BIG DELTA
TEST AREA
VEGETATION
Tall Forest
Mixed Short Forest
Mixed Scrub Forest
Sedge, Tussock
Tundra
0 1/2 1 2 3
MILES
146°00'
50'
40'
64° 00'
55'
50'
63° 45'
Batch Lake
M-110 c

Figure 2

## TABLE II: CLASSIFICATION OF PERENNIAL VEGETATION IN THE FORT GREELY TEST AREA

| GENERAL TYPE | HABITAT (S) | PRINCIPAL SPECIES | REMARKS |
|---|---|---|---|
| TALL FOREST | High moraine deposits | White and black spruce with scattered birch, aspen, and willow. | Occupies higher area between lakes. Density hinders transportation. |
| MIXED SHORT FOREST | Drier, gently sloping gravel plains which have been burned over. | Aspen and birch with scattered clumps of young spruce. | Young trees replaced spruce forest after forest fires. Cover is very dense and foot travel is difficult. |
| MIXED SCRUB | Usually on low poorly drained areas but sometimes found on slopes. | Alder, birch, and spruce with heath undergrowth. | Travel in winter easier than in mixed short forest. |
| SEDGE-TUSSOCK | Lowlands and bare hilltops. | Sedges on lowlands; mosses and lichens on hilltops. | One of the more accessible sections with roads and trails. Good for winter travel. |
| TUNDRA | Areas above 2,500 feet, | Tundra mosses, cranberry, blueberry, mossberry, small sedges and willows, labrador tea, and scattered alder and birch. | Steeper slopes show signs of solifluction and in places bare bedrock is exposed. |

2. Forest

Forest covers the largest part of the Big Delta Test Area. A spruce forest, with a thick heath undergrowth, covers level areas not disturbed by fire. In a large area south of the Big Delta Airport, the original spruce cover was destroyed by fire, but has been replaced by a birch-aspen forest with a heath undergrowth(mixed short forest.) Both the spruce and birch-aspen types of forest inhibit cross-country travel.

3. Mixed Scrub

Scrub growths of alder, birch, aspen and willow with heath undergrowth occupy parts of some lower areas where soils are poorly drained. Travel in the mixed scrub areas is much easier, both in summer and winter, than in the spruce and birch-aspen forests because of the weak, scrubby form of growth of the various species.

4. Sedge-Tussock*

Grass-like vegetation covers much of the wet, swampy lower parts of the kame-kettle sections. It may occur as a sedge-heath meadow formation on old lake surfaces that have been filled with peat, or as a tussock formation where very wet conditions exist. In both formations mosquitoes and black flies are a great nuisance from May through September.

5. Tundra

Tundra in this area may be called "shrubby tundra" as it is composed of mosses and lichens as well as scattered sedges, heath plants, and an occasional small willow, alder, or black spruce. This vegetation predominates at elevations above 2,000 feet in the southern part of the area, and in the Alaska Range farther south.

* Tussock or hummock muskeg may be defined as clumps of peat topped by sedge or other vegetation, interspersed with soft, wet clay.

## III. Weather and Climate

### A. Introduction

For extremely long-range forecasts, the science of meteorology has not progressed enough to provide reliable prognostications of the likely conditions of any one winter season. Climatology attempts to fill this gap through projections based on the historical record. However, climatology expresses its findings in terms of the probability of occurrence for specific weather phenomena - a definite improvement on chance occurrence to be sure, but not nearly as reliable a predictive device as the daily weather forecast. Test operators, therefore, are naturally concerned more with the actual weather forecast for the period they and their equipment will be present in the Fort Greely area. Nevertheless, results of climatological studies are used extensively as a basis for scheduling tests, particularly those dependent on low temperature occurrence such as cold weather tests of all types.

### B. Defining the Cold-Test Season

Army Regulation 70-38* outlines three levels of low temperature for design guidance in the RDT&E of materiel. These are: six continuous hours with an ambient air temperature of -25°F (4-6 feet above the ground) for the lower limit of "Intermediate Cold" conditions; six continuous hours with an ambient air-temperature of -50°F (also 4-6 feet above the ground) as the lower limit of "Cold"; and six continuous hours with an ambient air temperature of -70°F as the lower limit of "Extreme Cold." It follows, therefore, that the three temperature thresholds of concern to this study have been set at -25°F for Intermediate Cold, -50°F for Cold, and -70°F for Extreme Cold. The Arctic Test Center utilizes the -25°F threshold in definition of a "suitable" test day, as well as a -40°F threshold. The latter is used primarily because of the generally infrequent occurrence of -50°F at Fort Greely test sites.

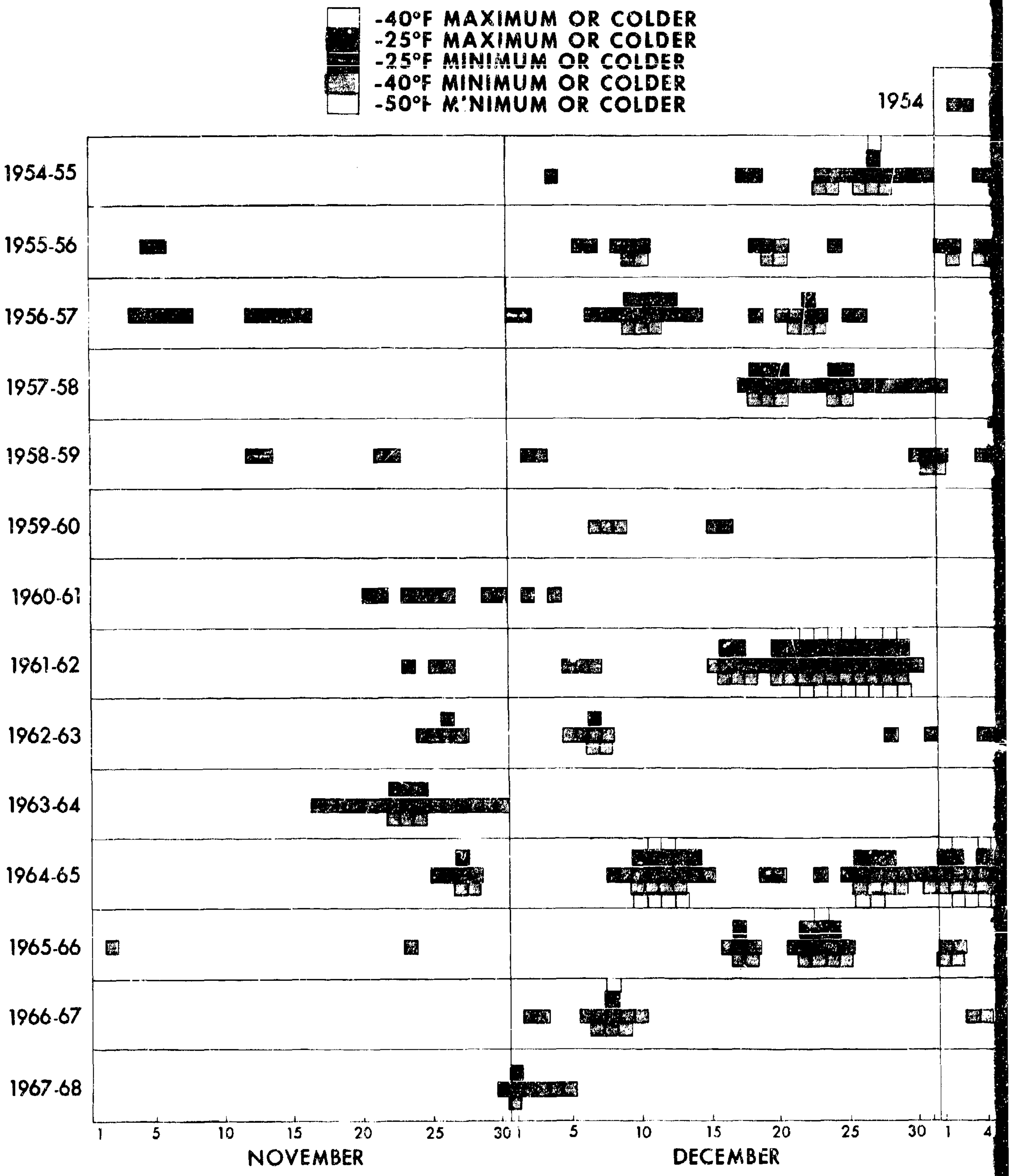
Figure 3 shows the frequency of occurrence of -25°F, -40°F, and -50°F maximum and minimum temperatures at Fort Greely for the years 1954 through 1968. In comparing the occurrences from year to year, it will be noted that -25°F minimum temperatures have been recorded from early in November to rather late in March. However, none of the five winter months represented has a guaranteed occurrence of a -25°F minimum in any one month. Indeed, on the average, about one winter month in three does not record a single -25°F minimum. The total number of -25°F minimum days ranged from a low of 13 days in the winter of 1959-60, to a high of 44 days during the winter of 1955-56. It should be remembered that lower temperatures than those recorded at

* See pp. 2-1 to 2-15, AR 70-38, 5 May 1969.

A

# OCCURRENCES OF -25°F, -40°F, AND -50°F

F



# -50°F MAXIMUM AND MINIMUM TEMPERATURES 19
## FORT GREELY, ALASKA

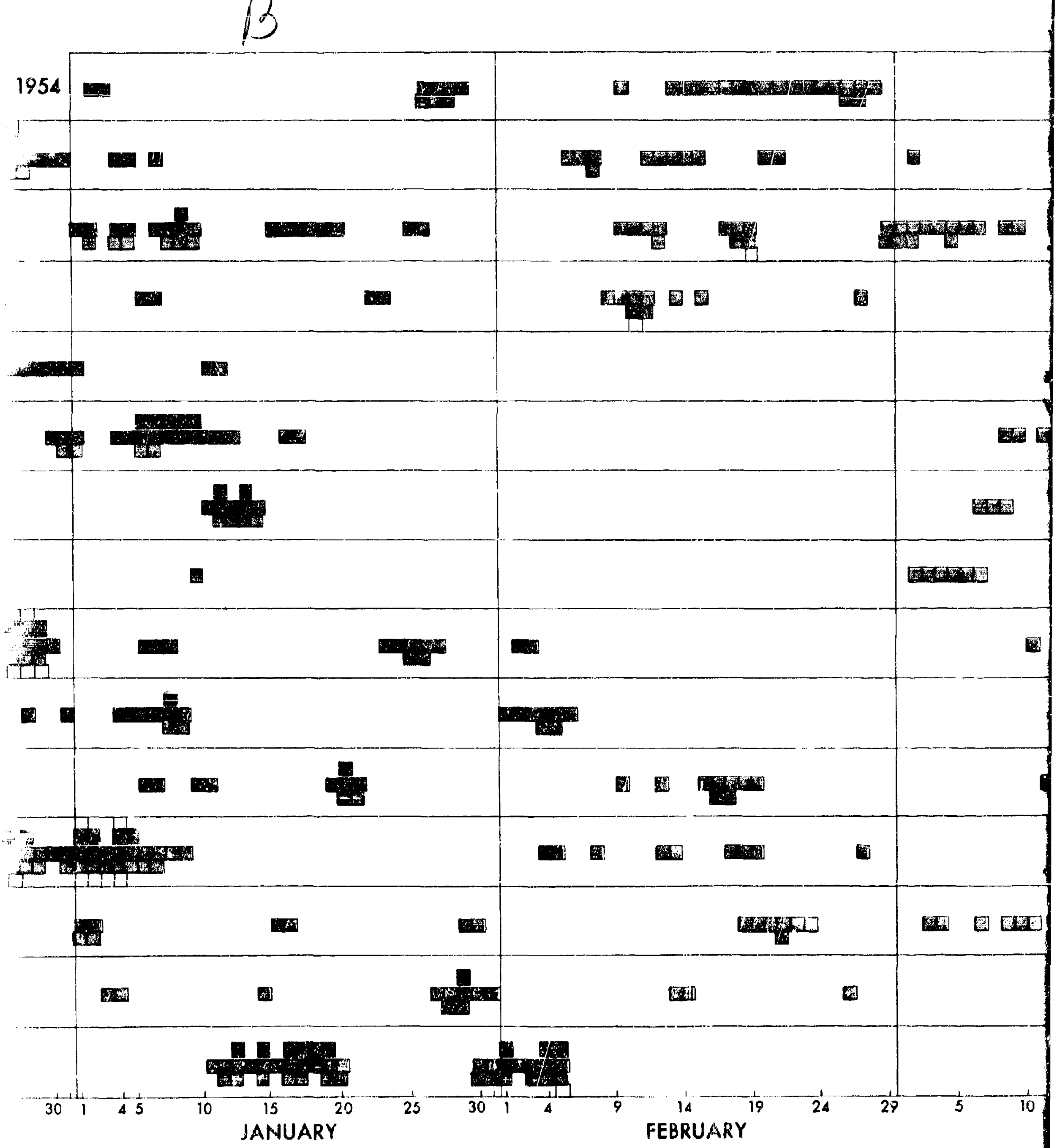
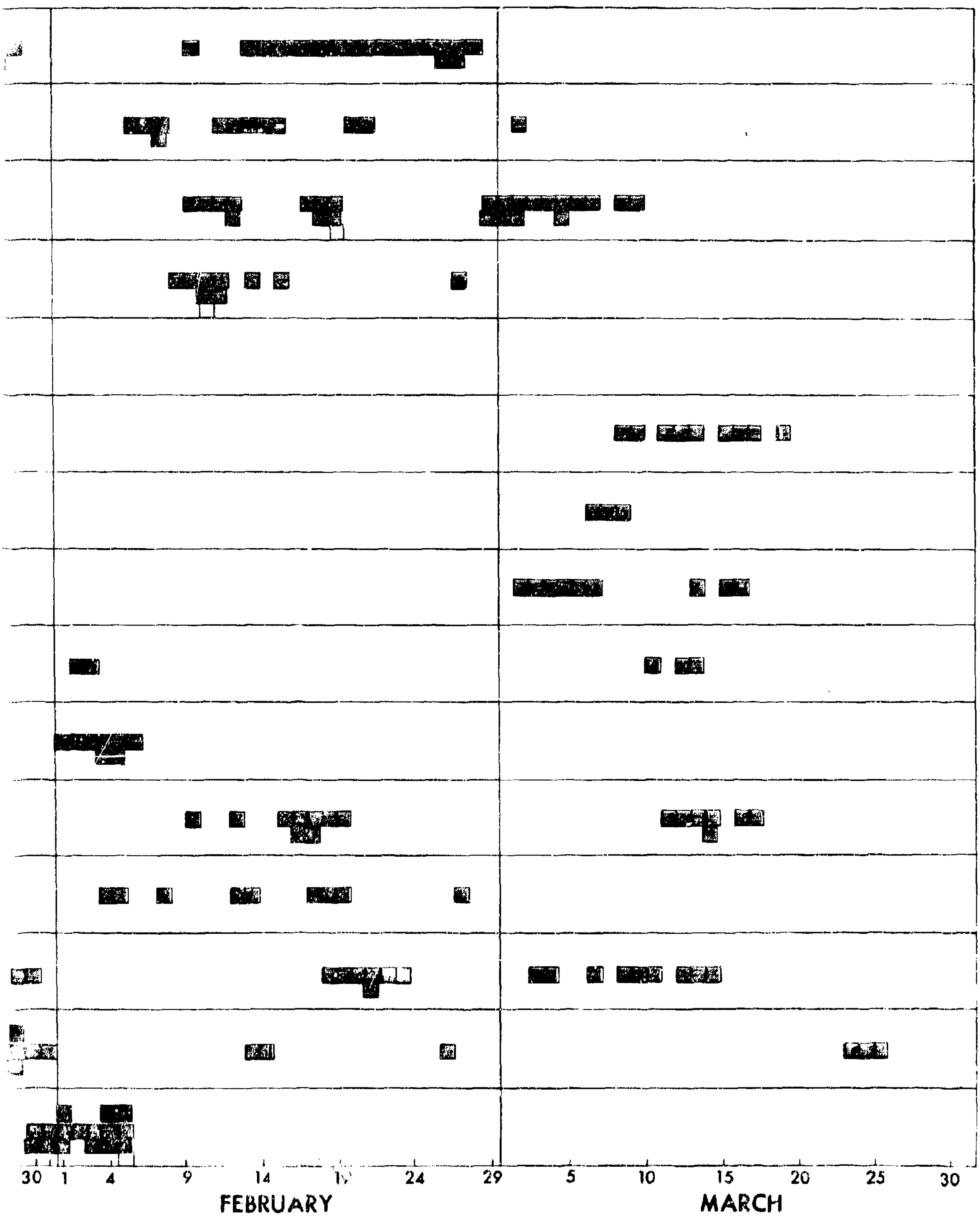



Figure 3

# MINIMUM TEMPERATURES 1954 - 1968

d



Fort Greely can and do occur at other sites like Bolio Lake and Butch Lake within the test area and therefore use of a -25°F minimum to define the cold test season at Fort Greely is justifiable. Maximum temperatures in the order of -50°F have not been recorded at Fort Greely during the period of record.

Figure 4 shows the frequency of occurrence of days with a minimum temperature of -25°F or lower for the same 15 winter seasons. This graph indicates that several definitions of the test season are possible. Considering that the temperature level in question is reached in spells of several consecutive days each at Fort Greely and not randomly by calendar date, the most obvious definition derivable is that the cold season is limited to the period of days during which the probability for experiencing a temperature -25°F or lower on any particular day is at least one in 15 (6.67%). This would limit the test season to the period from November 13th through March 18th. If one were to substitute -40°F for -25°F, and apply the same line of reasoning, the test season would be shortened to the period from November 22nd through March 15th. If one were to further stiffen requirements and insist that the chances for a -25°F temperature occurring must be at least two in 15 on any one date, then the principal test season would be confined to the period from November 22nd through January 21st. However, there are several short detached periods with days on which the chances for the occurrence of a -25°F temperature are at least two in 15 in February and early March, the most significant of which is the period from the 10th to the 23rd of February.

Assuming that the test operator is willing to wait an unspecified number of days for the occurrence of temperatures at or below -25°F at some test site in the Fort Greely area, the test season can be defined as the period from November 13th through March 18th. However, the later in the season the test occurs (February and March), the less likely is the probability of encountering prolonged cold with maximum and minimum temperatures of -25°F or lower (see Fig. 3). Furthermore, the increased insolation of February and March is also producing a solar heat load on equipment which may not be reflected in the ambient air temperatures. Therefore, it is advisable to utilize whatever opportunities arise for cold testing in middle to late November in a heavily-programmed test season.

## C. Solar and Lunar Illumination

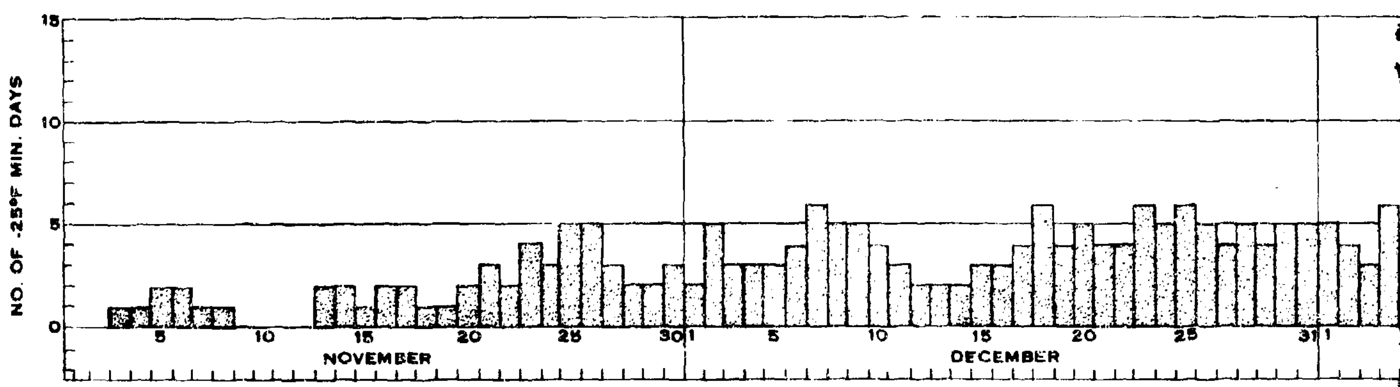
### 1. Solar Illumination

Figure 5 shows variations in the number of hours of darkness, twilight, and sunlight per day by month and season throughout the year. Very little need be said except to point out that the sun is very low over the southern horizon during winter, thereby causing considerable glare from snow-covered surfaces. Glare is particularly effective

H

# RELATIVE FREQUENCY OF -25°

# DATA FR



B

QUENCY OF -25°F OCCURRENCES - FORT GREELY, ALASK
DATA FROM 15 WINTERS 1954-1968

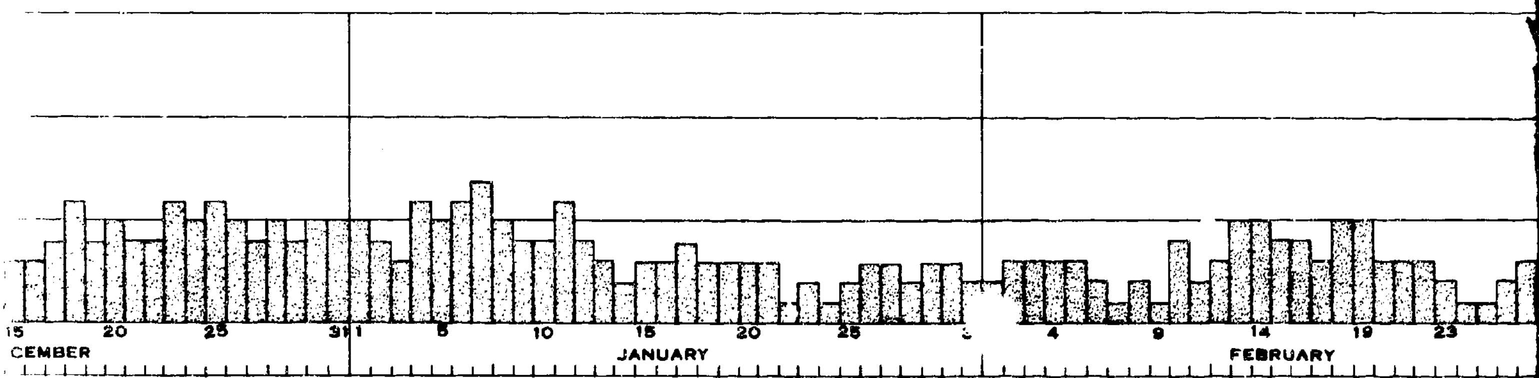
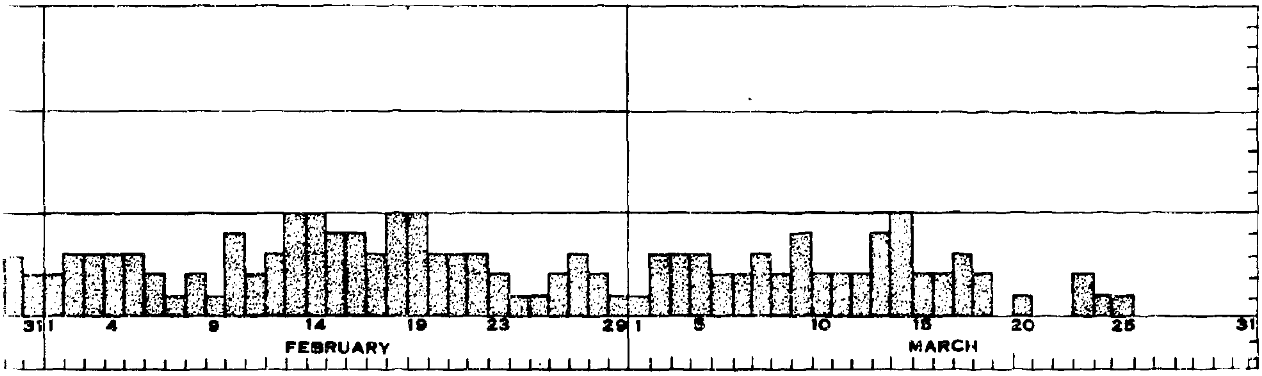



Figure 4

FORT GREELY, ALASKA

4-1968



# SUNLIGHT-DARKNESS GRAPH FOR FORT GREELY, ALASKA

LAT 63° 59'

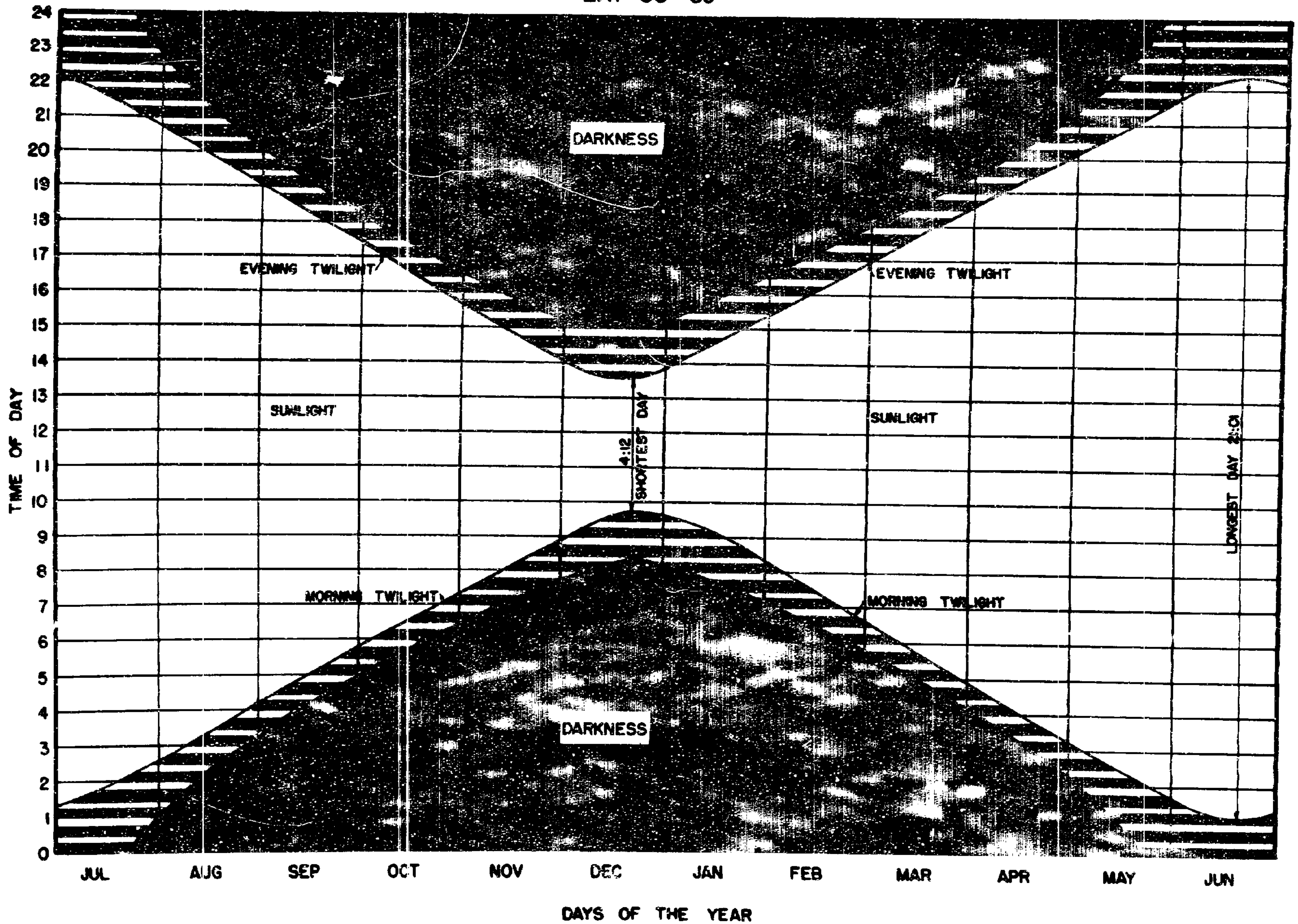



Figure 5

as a restriction to visibility when haze or ice fog is also present. Twilight is long at high latitudes and provides useful illumination for the test operator since this period of the day is relatively glare-free. The intensity of illumination during twilight is constantly changing as the sun moves ever lower (or higher) in relation to the horizon.

2. Lunar Illumination

Table III lists moon phase dates for the years from 1971 through 1980. Full moon provides the best illumination for test operations. Nevertheless, sufficient moonlight to conduct tests and observe results is provided as early as the 4th day preceeding and as late as the 4th day following full moon. It is also possible to see enough to negotiate most snow covered terrain even at half moon in the forested interior of Alaska. It is important that the landscape be snow covered. Clumps of forest in an otherwise snowy landscape detract from the total reflecting effectiveness of moonlight. Most Yukon-Tanana bush pilots in Alaska feel that only during the two or three nights when the moon is fullest is it really safe to land aircraft by moonlight. Moonlight actually provides some advantages over sunlight because of the absence of glare. Northern lights and star light sometimes add considerably to night illumination; however, they do not yield the sharp shadows produced by moonlight and are not predictable much in advance of their occurrence.

Table III does not include moon rise and moon set information for Fort Greely. However, because of the orbit of the moon relative to the axis of the earth, and the earth's orbit around the sun, the moon will always be highest in the sky and be visible longest when it is fullest during the winter test season. The two weeks when the moon is completely above the horizon in midwinter at the North Pole are also the two weeks when it is at its brightest. At Fort Greely in winter, the moon is highest in the sky at midnight on the date(s) of full moon. At noon, the full moon will be just below the horizon.

D. Weather During the Test Season

1. Pressure Systems and Their Influence on Interior Alaska Weather.

It is generally known that periods of stormy weather (cyclonic weather) alternate with periods of clear weather (anti-cyclonic weather), particularly in the middle and high latitudes and especially during the colder half of the year. This is generally true of Alaska, but interior sections - such as localities in the lee of the Chugach Mountains and the Alaska Range - are much less stormy and snowy than

TABLE III

Phases of the Moon - Winter Seasons

1971 - 1980

| | New Moon | | | | First Quarter | | | | Full Moon | | | | Last Quarter | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Day | Hour | Minute | | Day | Hour | Minute | | Day | Hour | Minute | | Day | Hour | Minute |
| **1971** | | | | | | | | | | | | | | | |
| Jan | 26 | 22 | 55 | Jan | 4 | 04 | 56 | Jan | 11 | 13 | 21 | Jan | 19 | 18 | 09 |
| Feb | 25 | 09 | 49 | Feb | 2 | 14 | 32 | Feb | 10 | 07 | 42 | Feb | 18 | 12 | 14 |
| Mar | 26 | 19 | 24 | Mar | 4 | 02 | 02 | Mar | 12 | 02 | 34 | Mar | 20 | 02 | 31 |
| Oct | 19 | 08 | 00 | Oct | 27 | 05 | 55 | Oct | 4 | 12 | 21 | Oct | 11 | 05 | 30 |
| Nov | 18 | 01 | 46 | Nov | 25 | 16 | 37 | Nov | 2 | 21 | 21 | Nov | 9 | 20 | 52 |
| Dec | 17 | 19 | 03 | Dec | 25 | 01 | 36 | Dec | 2 | 07 | 49 | Dec | 9 | 16 | 03 |
| | | | | | | | | Dec | 31 | 20 | 21 | | | | |
| **1972** | | | | | | | | | | | | | | | |
| Jan | 16 | 10 | 54 | Jan | 23 | 09 | 29 | Jan | 30 | 10 | 59 | Jan | 8 | 13 | 32 |
| Feb | 15 | 00 | 29 | Feb | 21 | 17 | 21 | Feb | 29 | 03 | 13 | Feb | 7 | 11 | 12 |
| Mar | 15 | 11 | 35 | Mar | 22 | 02 | 13 | Mar | 29 | 20 | 06 | Mar | 8 | 07 | 06 |
| Oct | 7 | 08 | 09 | Oct | 15 | 12 | 55 | Oct | 22 | 13 | 26 | Oct | 29 | 04 | 41 |
| Nov | 6 | 01 | 21 | Nov | 14 | 05 | 01 | Nov | 20 | 23 | 08 | Nov | 27 | 17 | 45 |
| Dec | 5 | 20 | 25 | Dec | 13 | 18 | 36 | Dec | 20 | 09 | 46 | Dec | 27 | 10 | 28 |
| **1973** | | | | | | | | | | | | | | | |
| Jan | 4 | 15 | 43 | Jan | 12 | 05 | 28 | Jan | 18 | 21 | 30 | Jan | 26 | 06 | 06 |
| Feb | 3 | 09 | 23 | Feb | 10 | 14 | 06 | Feb | 17 | 10 | 07 | Feb | 25 | 03 | 12 |
| Mar | 5 | 00 | 08 | Mar | 11 | 21 | 26 | Mar | 18 | 23 | 34 | Mar | 26 | 23 | 48 |
| Oct | 26 | 03 | 17 | | | | | Oct | 12 | 03 | 10 | Oct | 18 | 22 | 34 |
| Nov | 24 | 19 | 56 | Nov | 3 | 06 | 30 | Nov | 10 | 14 | 28 | Nov | 17 | 06 | 35 |
| Dec | 24 | 15 | 07 | Dec | 3 | 01 | 30 | Dec | 10 | 01 | 36 | Dec | 16 | 17 | 14 |

TABLE III (cont'd)

Phases of the Moon

| | New Moon | | | | First Quarter | | | | Full Moon | | | | Last Quarter | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | H | M | | D | H | M | | D | H | M | | D | H | M |
| **1974** | | | | | | | | | | | | | | | |
| Jan | 23 | 11 | 03 | Jan | 1 | 18 | 07 | Jan | 8 | 12 | 37 | Jan | 15 | 07 | 04 |
| Feb | 22 | 05 | 35 | Jan | 31 | 07 | 40 | Feb | 6 | 23 | 25 | Feb | 14 | 00 | 05 |
| Mar | 23 | 21 | 25 | Mar | 1 | 18 | 03 | Mar | 8 | 10 | 04 | Mar | 15 | 19 | 15 |
| | | | | Mar | 31 | 01 | 45 | Oct | 1 | 10 | 38 | | | | |
| Oct | 15 | 12 | 25 | Oct | 23 | 01 | 54 | Oct | 31 | 01 | 20 | Oct | 8 | 19 | 46 |
| Nov | 14 | 00 | 53 | Nov | 21 | 22 | 40 | Nov | 29 | 15 | 11 | Nov | 7 | 02 | 48 |
| Dec | 13 | 16 | 26 | Dec | 21 | 19 | 44 | Dec | 29 | 03 | 51 | Dec | 6 | 10 | 11 |
| **1975** | | | | | | | | | | | | | | | |
| Jan | 12 | 10 | 21 | Jan | 20 | 15 | 15 | Jan | 27 | 15 | 11 | Jan | 4 | 19 | 05 |
| Feb | 11 | 05 | 18 | Feb | 19 | 07 | 40 | Feb | 26 | 01 | 15 | Feb | 3 | 06 | 23 |
| Mar | 12 | 23 | 48 | Mar | 20 | 20 | 05 | Mar | 27 | 10 | 37 | Mar | 4 | 20 | 21 |
| Oct | 5 | 03 | 23 | Oct | 12 | 01 | 16 | Oct | 20 | 05 | 06 | Oct | 27 | 22 | 08 |
| Nov | 3 | 13 | 05 | Nov | 10 | 18 | 21 | Nov | 18 | 22 | 29 | Nov | 26 | 06 | 52 |
| Dec | 3 | 00 | 50 | Dec | 10 | 14 | 40 | Dec | 18 | 14 | 40 | Dec | 25 | 14 | 53 |
| **1976** | | | | | | | | | | | | | | | |
| Jan | 1 | 14 | 41 | Jan | 9 | 12 | 40 | Jan | 17 | 04 | 47 | Jan | 23 | 23 | 05 |
| Jan | 31 | 06 | 21 | | | | | | | | | | | | |
| Feb | 29 | 23 | 26 | Feb | 8 | 10 | 06 | Feb | 15 | 16 | 44 | Feb | 22 | 08 | 16 |
| Mar | 30 | 17 | 08 | Mar | 9 | 04 | 39 | Mar | 16 | 02 | 53 | Mar | 22 | 18 | 56 |
| Oct | 23 | 05 | 10 | Oct | 29 | 22 | 06 | Oct | 8 | 04 | 56 | Oct | 16 | 09 | 00 |
| Nov | 21 | 15 | 12 | Nov | 28 | 13 | 00 | Nov | 6 | 23 | 16 | Nov | 14 | 22 | 40 |
| Dec | 21 | 02 | 09 | Dec | 28 | 07 | 49 | Dec | 6 | 18 | 15 | Dec | 14 | 10 | 15 |
| **1977** | | | | | | | | | | | | | | | |
| Jan | 19 | 14 | 12 | Jan | 27 | 05 | 12 | Jan | 5 | 12 | 11 | Jan | 12 | 19 | 55 |
| Feb | 18 | 03 | 38 | Feb | 26 | 02 | 51 | Feb | 4 | 03 | 57 | Feb | 11 | 04 | 08 |
| Mar | 19 | 18 | 33 | Mar | 27 | 22 | 27 | Mar | 5 | 17 | 14 | Mar | 12 | 11 | 35 |
| Oct | 12 | 20 | 31 | Oct | 19 | 12 | 47 | Oct | 26 | 23 | 36 | | | | |
| Nov | 11 | 07 | 10 | Nov | 17 | 21 | 53 | Nov | 25 | 17 | 32 | Nov | 4 | 03 | 59 |
| Dec | 10 | 17 | 34 | Dec | 17 | 10 | 38 | Dec | 25 | 12 | 50 | Dec | 3 | 21 | 16 |

TABLE III (cont'd)

Phases of the Moon

| | New Moon | | | | First Quarter | | | | Full Moon | | | | Last Quarter | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | D | H | M | | D | H | M | | D | H | M | | D | H | M |
| **1978** | | | | | | | | | | | | | | | |
| Jan | 9 | 04 | 01 | Jan | 16 | 03 | 04 | Jan | 24 | 07 | 56 | Jan | 2 | 12 | 08 |
| Feb | 7 | 14 | 56 | Feb | 14 | 22 | 12 | Feb | 23 | 01 | 27 | Jan | 31 | 23 | 52 |
| Mar | 9 | 02 | 37 | Mar | 16 | 18 | 21 | Mar | 24 | 16 | 21 | Mar | 2 | 08 | 35 |
| Oct | 2 | 06 | 42 | | | | | | | | | Mar | 31 | 15 | 11 |
| Oct | 31 | 20 | 07 | Oct | 9 | 09 | 38 | Oct | 16 | 06 | 10 | Oct | 24 | 00 | 35 |
| Nov | 30 | 08 | 20 | Nov | 7 | 16 | 19 | Nov | 14 | 20 | 01 | Nov | 22 | 21 | 25 |
| Dec | 29 | 19 | 37 | Dec | 7 | 00 | 35 | Dec | 14 | 12 | 32 | Dec | 22 | 17 | 42 |
| **1979** | | | | | | | | | | | | | | | |
| Jan | 28 | 06 | 20 | Jan | 5 | 11 | 15 | Jan | 13 | 07 | 09 | Jan | 21 | 11 | 24 |
| Feb | 26 | 16 | 46 | Feb | 4 | 00 | 37 | Feb | 12 | 02 | 40 | Feb | 20 | 01 | 18 |
| Mar | 28 | 03 | 00 | Mar | 5 | 16 | 23 | Mar | 13 | 21 | 15 | Mar | 21 | 11 | 23 |
| Oct | 21 | 02 | 24 | Oct | 28 | 13 | 07 | Oct | 5 | 19 | 37 | Oct | 12 | 21 | 25 |
| Nov | 19 | 18 | 04 | Nov | 26 | 21 | 09 | Nov | 4 | 05 | 48 | Nov | 11 | 16 | 24 |
| Dec | 19 | 08 | 24 | Dec | 26 | 05 | 12 | Dec | 3 | 18 | 09 | Dec | 11 | 14 | 00 |
| **1980** | | | | | | | | | | | | | | | |
| Jan | 17 | 21 | 21 | Jan | 24 | 13 | 59 | Jan | 2 | 09 | 04 | Jan | 10 | 11 | 51 |
| Feb | 16 | 08 | 51 | Feb | 23 | 00 | 15 | Feb | 1 | 02 | 22 | Feb | 9 | 07 | 37 |
| Mar | 16 | 18 | 57 | Mar | 23 | 12 | 32 | Mar | 1 | 21 | 00 | Mar | 9 | 23 | 49 |
| | | | | | | | | Mar | 31 | 15 | 15 | | | | |
| Oct | 9 | 02 | 51 | Oct | 17 | 03 | 49 | Oct | 23 | 20 | 53 | Oct | 30 | 16 | 34 |
| Nov | 7 | 20 | 43 | Nov | 15 | 15 | 47 | Nov | 22 | 06 | 40 | Nov | 29 | 10 | 00 |
| Dec | 7 | 14 | 36 | Dec | 15 | 01 | 48 | Dec | 21 | 18 | 09 | Dec | 29 | 06 | 33 |

exposed coastal areas to the south. Most Alaskan storms (cyclones) that affect the mainland are guided by upper air troughs (see Fig. 6) which usually travel from west to east at varying rates of speed. Most of the precipitation and cloudy weather occur to the east of the trough and are accompanied by southerly winds from the Pacific Ocean or the Bering Sea. High pressure ridges located to the west of the trough signal the approach of clear cold air from the northwest. Under these conditions the clear air and cloudless skies permit considerable heat loss by radiation and inversion (colder air near the ground). This is the typical situation in which cold spells occur. The longest cold spells occur when the trough moves very slowly or becomes semi-stationary to the east of central Alaska. Normal or "average" weather usually occurs during periods of transition from one weather type to another and is, therefore, only an indication of change.

2. Average Weather Conditions on Days Reporting Special Phenomena

Table IV shows average values for selected elements on days when special weather situations predominate for the three mid-winter months of the years 1964 to 1968. It will be noted that neither snowfall nor snowcover amounts are very great, as is typical of most Arctic and sub-arctic locations. Snowy weather is neither very cold nor very prolonged but does occur fairly frequently. Cloudy skies and moderately strong winds with a southerly component are typical of snowy weather at Fort Greely.

Cloudy days are much more frequent than clear days and are generally warmer. Wind velocities are higher, on the average, during clear days than cloudy days, due to a number of factors including down-valley air drainage and over-riding of the Arctic inversion by maritime air masses.

Fully one-fourth of all winter days are too warm for any kind of cold weather testing. However, acceptable cold-testing days occur about as frequently, and generally, they occur in spells of several days each. Furthermore, the acceptable cold-testing days usually have many consecutive hours of lowered temperatures so that acceptable cold-soaking of equipment can take place. It should be remembered that the statistics on cold occurrence in Table IV represent the main weather station at Ft. Greely, and not available sites nearby where temperatures on the average are lower.

3. The Stability of the Diurnal Temperature Cycle.

Table V illustrates the stability of the diurnal temperature cycle at Ft. Greely during mid-winter (January). The mean temperature difference between the warmest and coldest parts of the day is only 3.3°F. More important, perhaps, are the large standard deviations of temperature for each of the time divisions given. Both the modal class

## IDEALIZED, FREQUENTLY OCCURRING 500MB. FLOW PATTERN ASSOCIATED WITH THE OCCURRENCE OF DEEP COLD IN CENTRAL ALASKA*

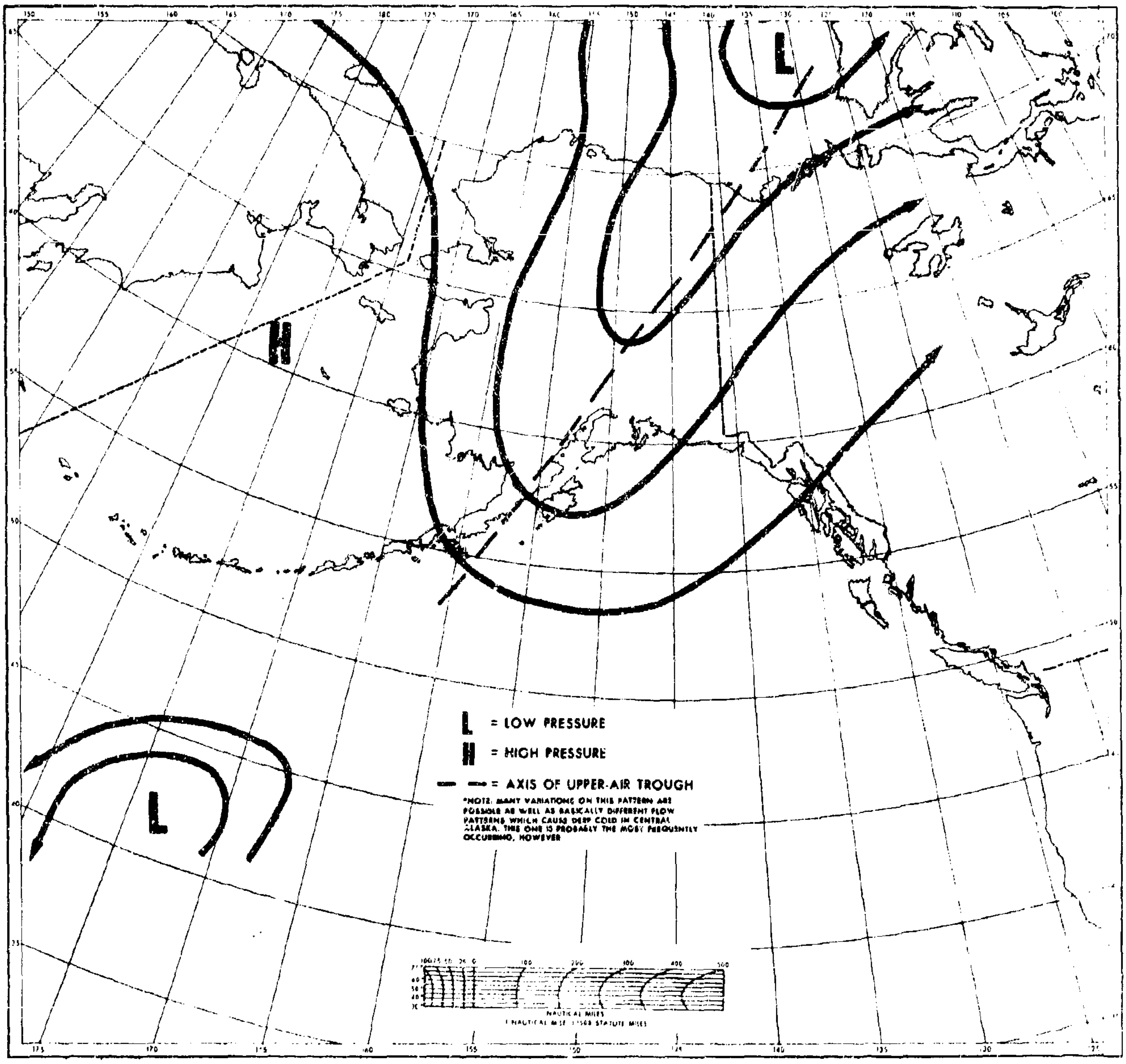



**Figure 6**

TABLE IV

Average Weather Conditions on Days Reporting:

FRESH SNOWFALL

Days with Precip. of more than a Trace

| | | | | | |
|---|---|---|---|---|---|
| Total no. of Days | 88 | Percentage of Days Studied | 21% | Mean precip. per precip. day (Inches of Snow) | 1.2" |

| | |
|---|---|
| Av. Max. Temp. | 7.6°F |
| Av. Min. Temp. | -7.2°F |
| Median Wind Direction | 187° (South) |
| Mean Wind Direction | 220° (Southwest) |
| Average Fastest Mile | 14.4 mph |
| Mean Sky Cover (10ths) | 8.8 |
| Av. no. of consecutive days with Snowfall ≥ Trace | 1.7 days |
| Greatest number of consecutive days with snowfall ≥ Trace in sample period | 4 days |

FALLING SNOW

Days with Precip. of Trace or More

| | | | | | |
|---|---|---|---|---|---|
| Total no. of Days | 188 | Percentage of Days Studied | 45% | Mean precip. per precip. day (Inches of Snow) | .6" |

| | |
|---|---|
| Av. Max. Temp. | 4.0°F |
| Av. Min. Temp. | -12.5°F |
| Median Wind Direction | 158° (SSE) |
| Mean Wind Direction | 200° (SSW) |
| Average Fastest Mile | 15.3 mph |
| Mean Sky Cover (10ths) | 7.9 |
| Av. No. of consecutive days with Snowfall ≥ Trace | 2.8 days |
| Greatest number of consecutive days with snowfall ≥ Trace in sample period | 8 days |

TABLE IV (Cont'd)

COLD (ACCEPTABLE COLD TEST)

Days with Min. Temp. of -25°F or lower

| | | | | | |
|---|---|---|---|---|---|
| Total no. of Days | 112 | Percentage of Days Studied | 26.6% | Mean Min. Temp. of Days studied | -38.0°F |

| | |
|---|---|
| Av. 24 hr. temp. of such days | -27.7°F |
| Mean Wind Direction of such days | 162° (SSE) |
| Mean Wind Speed of such days | 7.7 mph |
| Av. Fastest Mile of such days | 15.2 mph |
| Mean sky cover of such days | 3.8ths |
| Av. No. of consecutive days with -25°F Min. or lower | 3.62 days |
| Greatest No. of consecutive days with -25°F or lower in sample period | 16 days |
| Longest period of continuous -25°F temp. in sample period | 11 days or 264 hrs. |

WIND & WINDCHILL

Days with Av. Wind Velocity of 20 Mph or More

| | | | | | |
|---|---|---|---|---|---|
| Total no. of Days | 93 | Percentage of Days Studied | 22% | Mean Wind Vel. of Such Days | 24.9 mph |

| | |
|---|---|
| Av. Min Temp. on such days | -3.9°F |
| Av. 24 hr. Temp. of such days | 1.7°F |
| Prevailing Wind Direction | 121° (ESE) |
| Av. Fastest Mile | 35.2 mph |

CLEAR DAYS

Days with Av. Cloud Cover of 3/10ths or less

| | | | | | |
|---|---|---|---|---|---|
| Total no. of Days | 122 | Percentage of Days Studied | 29% | Mean Cloud Cover of Such Days | 1.3 tenths |

| | |
|---|---|
| Av. Min. Temp on such days | -26.1°F |
| Mean Wind Speed | 13.5 mph |
| Av. Fastest Wind Speed | 22.5 mph |

TABLE IV (Cont'd)

UNACCEPTABLE COLD TEST DAYS

Days with Min. Temp. of 0°F or Higher

| | | | | | |
|---|---|---|---|---|---|
| Total no. of Days | 106 | Percentage of Days Studied | 25.2% | Mean Min. Temp. on Such Days | 12.0°F |

| | |
|---|---|
| Av. 24 hr. temp. of such days | 18.2°F |
| Av. No. of consecutive days with Min. Temp. of 0°F or above | 3.42 |
| Greatest No. of consecutive days with min. temp. of 0°F or above in sample period | 11 days |

SNOW COVER

Days with snow cover

| | | | | | |
|---|---|---|---|---|---|
| Total no. of Days | 421 | Percentage of Days Studied | 100% | Mean Snowcover | 9.9" |

CLOUDY DAYS

Days with Av. Cloud Cover of 8/10ths or more

| | | | | | |
|---|---|---|---|---|---|
| Total no. of Days | 176 | Percentage of Days Studied | 41.8% | Mean Cloud Cover of such days | 9.1 tenths |

| | |
|---|---|
| Av. 24 hr. Temp. of such days | 3.4°F |
| Mean Wind Speed of such days | 10.7 mph |
| Av. No. of consecutive days with cloud cover of 8/10ths or more | 2.2 days |
| Greatest No. of consecutive days with cloud cover 8/10ths or more in sample period | 7 days |

## TABLE V

DIURNAL TEMPERATURE STATISTICS--BIG DELTA, JANUARY 1951-1960

| Time of Obs. | 00-02 | 03-05 | 06-08 | 09-11 | 12-14 | 15-17 | 18-20 | 21-23 |
|---|---|---|---|---|---|---|---|---|
| Mean Temp (°F) | -6.4 | -6.5 | -6.8 | -6.0 | -3.5 | -4.9 | -5.4 | -5.8 |
| Standard Dev. (°F) | 18.38 | 18.37 | 18.41 | 18.30 | 17.22 | 17.75 | 18.21 | 18.42 |
| Modal Class (°F) | 5°/6° | 3°/4° | -2°/-3° | 3°/4° | 5°/6° | 1°/2° | 1°/4° | 5°/6° |
| Abs. Range of Variation (°F) | +34 to -53 | +36 to -53 | +34 to -51 | +36 to -51 | +34 to -45 | +34 to -51 | +36 to -51 | +36 to -51 |
| No. of Obs. | 930 | 929 | 930 | 929 | 930 | 930 | 930 | 929 |

values as well as the range-of-variation data by division also emphasize the fact that deep cold and unusual warmth can and do occur at any hour. It may be concluded, therefore, that control by air-mass advection is more important than the insolation cycle in determining when cold spells suitable for cold testing will occur.

December data, in all probability, closely match the January data for the categories given. During February and March, however, when days are lengthening and the sun is higher, greater diurnal differences should be evident. Once again, these data underscore the fact that weather, including cold-testing weather, occurs in spells.

4. Local Influences on Atmospheric Conditions at Ft. Greely

Owing to small scale variations of weather induced by local influences, test operators would be well advised to scour the countryside, both within and about Ft. Greely, for sites offering the best possibilities for satisfying the particular set of environmental test conditions in question. In certain instances, the difference between success and failure in attaining given environmental objectives, may be merely a matter of choosing judiciosly between two sites a short distance apart. To help the test planner make the right decision, pertinent information on influences affecting local weather at Ft. Greely is given below.

a. Foehn Winds

When air is forced to flow through a narrow mountain passage such as Isabel Pass it is compressed, and, as it descends into the valley beyond, it warms at the rate of 5F° for each 1,000 feet of descent. This warmer air flows down valley from the pass accompanied by gusty winds. Locally this flow of warm air is known as the "Chinook". The edges of the descending warm air mass are generally sharply defined, so that one can actually drive back and forth across the boundary and experience abrupt changes in temperature, wind velocity, and gustiness, as well as wind direction. Obviously for cold testing purposes of the cold soak variety, the occurrence of the Chinook reduces the likelihood of very low temperatures even though dangerously high wind chill values can occur in association with this type of flow.*

Major low pressure storms located south or west of central Alaska are highly indicative of conditions favorable for the development of Chinook winds. These storm cells must occur in association with a high pressure center positioned over northern or eastern Alaska causing a tightened pressure gradient over Big Delta. In general, a 3mb

*Mitchell, J.M., Strong Surface winds at Big Delta, Alaska--An Example of Orographic Influence on Local Weather, Mo. Wea. Rev. 84: p. 19 (Jan 1956)

pressure difference between Northway and Big Delta suffices to predict commencement of ESE winds of 20 mph or more. The more sourtherly the high winds at Big Delta, the greater the probability that they will be accompanied by a foehn-wall cloud formation over the mountains of the Alaska Range to the south. Owing to the unusual development and movement of pressure systems in Alaska, and the exact orientation of the mountain pass to the south, the warm chinook current generally moves out into the Tanana Plain at a point west of Big Delta, rather than at Big Delta itself. The Chinook not only advects heat into the Ft. Greely area, but it also destroys the normal Arctic temperature inversions to further raise temperatures at ground level.

b. <u>Temperature Changes with Increasing Elevation</u>

Most people are familiar with the fact that the higher the surface elevation, the colder one's environment until finally the snowline is reached. On an annual basis this drop in temperature, computed for the world in general, averages 3.6F° per 1000 feet of elevation increase (normal lapse rate). The vegetational changes on both the Alaska Range and Donnelly Dome are reflections of the effects of this temperature decline. As has been pointed out however, it is possible for warmer air to override cooler air, causing a reversal of the normal decline of temperature with increasing elevation. Two of the most important causal factors for this type of anomaly in the Ft. Greely area are <u>cold air drainage</u> and the <u>Arctic inversion</u>.

1. <u>Cold Air Drainage</u>

During the long Arctic nights enormous amounts of dense cold air collect in the interior valleys such as the Tanana. This cold air may have been advected from the north, in conjunction with an outbreak of Arctic air, generated in place through radiation, or accumulated through local downslope flow from adjacent uplands. In any case, this denser and colder air tends to accumulate to depths from several hundred to a thousand and more feet wherever the combination of topography and pressure gradients permit. This means that during prolonged periods of calm clear weather, particularly those preceded by snowfall, it is not unusual for cold air to accumulate in lowlands and valleys to depths capable of sustaining a temperature inversion as much as 20F° from the base to the top of a hill such as Donnelly Dome. Even on the flat interfluvial surfaces such as the sites of Big Delta/Ft. Greely, cold air may drain into the riverine lowlands, leaving the site 10 to 15F° warmer than the adjacent river flats.

This phenomenon of air drainage sometimes creates a noticeable breeze during times of deep cold and is responsible for an increase in local wind chill values, especially on the slopes adjacent to river flats. This same phenomenon will create a gentle down-valley breeze which can become quite strong in constricted sections of the valley where hills or bluffs tend to pinch out or dam the flow of air.*

### 2. The Arctic Inversion

Because surface inversions exist in many areas much of the time, they tend to cause warmer air moving into the region to glide over the cold dense air trapped in the lowland pockets, leaving the colder air undisturbed to levels as high as 2 kms. This semi-permanent winter phenomenon is termed the Arctic inversion. At protected inland sites such as Fairbanks the Arctic inversion depresses surface temperatures to levels about 5 to 10F° below the normals for comparably located but inversion-free sites. This means then, that gradually warming temperatures will normally be encountered as one moves upslope on hillsides from lowland locations within interior Alaska.

### c. Wind as a Low Temperature Deterrent

In addition to the gusty winds associated with the warming Chinook, winds blowing out of major storm centers also exert disruptive effects on conditions that breed extremely cold weather in the Ft. Greely area. In such situations, destruction of the inversion layer itself is the principal reason for the termination of cold weather. As stated earlier cold air tends to accumulate in pockets and valleys and warmer advecting air tends to override the colder air. But this is so only if the advection of warmer air is rather gentle with resulting laminar flow. Strong winds associated with the passage of a major storm coming off the ocean generate a great deal of mechanical turbulence in the air, the result of the air moving rapidly past such terrain features as Donnelly Dome or Granite Mountain. This turbulent air is characterized by many horizontal and vertical eddies. The scouring action of the eddies lifts the cold air lying close to the surface and mixes it with the warmer air above. At the same time warmer air gradually replaces the cold air that has been forced aloft, so that the warmest air is positioned next to and immediately above the surface. A narrow steep-sided canyon would tend to be relatively free from this action, especially if it happened to be oriented at right angles to the air flow. This is one reason why Snag (Yukon Territory, Canada) is one of the coldest stations

*Ehrlich, A. Note on Local Winds Near Big Delta, Alaska, Bull. Amer. Meteor Soc. 34: 181-82 (Apr. 1953)

in North America. Northway in Alaska is more exposed than Snag, but still experiences a much higher frequency of weather conditions suitable for cold testing than does Ft. Greely.*

d. Wind Chill

Wind chill is a significant environmental factor to be measured during the testing of clothing and all types of shelter that must be heated to maintain comfortable inside temperatures. Wind chill, of course, is that part of the total cooling of a body or object caused by the motion of air. It is expressed as the loss of heat in kilogram calories per hour per square meter of exposed surface and is based on the cooling rate of a body in the shade. The measurement and expression of wind chill will be taken up in a later section. Physiologically it accounts for up to 80 percent of the total body heat loss; other avenues of heat loss such as evaporation account for most of the remainder. Some of the highest wind speeds on record for Alaska have been experienced at Ft. Greely. Because of its location in a long valley leeward of a mountain pass it is in the path of rapidly moving air from the pass where compaction has accelerated the air flow. Although strong winds constitute a hazard to many tests, they benefit others such as wind chill tests which cannot be conducted without air in motion.

Based upon winter data for 1961-1968, Ft. Greely has a mean January wind chill value of 1450. Normally, monthly values of wind chill are highest in January, but in certain years values as high or higher are reported for December. However, because there is a marked tendency for the lowest temperatures to be accompanied by the lowest wind velocities and the highest winter temperatures to be accompanied by relatively high wind velocities, mean monthly wind chill values tell little about possible extremes of windchill. Figure 7 shows the daily wind chill values at Ft. Greely for 791 winter days from 1 January 1961 through 29 February 1968. The daily record yields far more information about wind chill variability than does the record of mean monthly values. For example, the conclusions stated below were arrived at through study of the daily records.

1) Of all wind chill values greater than 1700 kg. cal./m²/hr., 58.8% occurred in January, 23.7% in December, and only 17.5% in February.

2) Of all wind chill values greater than 1700, not one such daily computation was made for January 1968, indicating high variability from year to year.

*During every January, from 1945 through 1962, Northway registered more -25°F cold hours than did Big Delta, with the average January showing 124% more hours below this testing threshold than is experienced at Big Delta.

## DAILY WINDCHILL VALUES AT FT. GREELY FOR SEVEN CONSECUTIVE WINTERS (DEC, JAN, FEB) FROM 1961 TO 1968

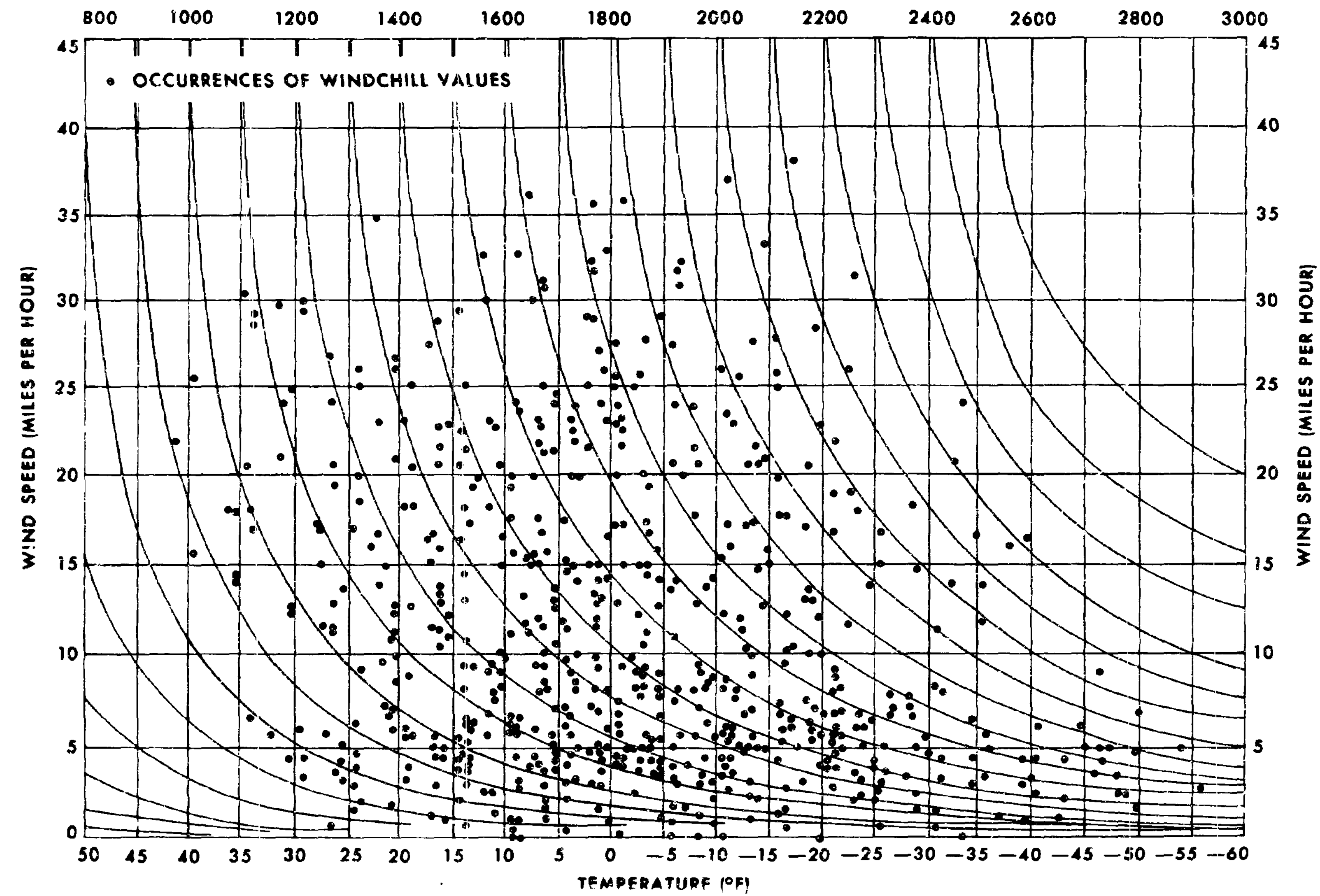



Figure 7

3) The highest wind chill value computed for any day in the eight year period of study was a relatively modest 2254 for 14 December 1964. This value does not compare favorably with extremes reached in Antarctica, North Central Canada, or Greenland.

4) Ten percent of all January days registered wind chill values below 900 (just barely "cold"), and 10% were above 1900, the "dangerous" level. This means that 80% of all daily values for January fall between 900 and 1900 kg. cal./m²/hr.

The highest daily and mean January wind chill values obtained in Alaska were computed for stations along the Arctic Coast (i.e., Barrow, Barter Island). Comparable figures for Ft. Greely are not nearly so extreme, yet the wind chill factor is intense enough to meet the minimum requirements for most tests. If necessary, high degrees of wind chill can be induced either by way of a vehicle driven rapidly through cold air or via the controlled environment of a test chamber.

e. Oceanic Influences and Snow

The incursion of maritime air masses from the open Pacific Ocean also exerts a profound influence on weather conditions at Ft. Greely. For example, whenever there is a strong and protracted westerly flow of air up the Tanana Valley from the Bering Sea, snow (or rain) will occur at Ft. Greely. This precipitation is invariably characterized as light or very light. Nevertheless, snowfall frequently measures 2 to 16 inches per storm. The synoptic weather situations which give rise to westerly flow are rather long-lived and the average snowstorm lasts about three days.

Since practically all of the precipitation in the Ft. Greely area is at least partly due to orographic lifting by hills and mountains, the surrounding terrain largely determines the pattern of snowfall. The snowfall at Ft. Greely is representative of the surrounding plain, but not at all of the nearby heights where the fall is much heavier. Typical of the heavy upland snows is that received at the Black Rapids Training Site of the Army's Northern Warfare Training Center. Here, the westerly flow of moist air is compressed by the narrow Black Rapids Canyon and delivers up its moisture at a rapid rate. Even when the flow is southerly, Black Rapids often receives snow when Ft. Greely does not.*

As a result of wind action on the light snow of the Ft. Greely area, some open areas remain nearly clear of snow throughout the winter. In forested areas, however, snow forms a lasting cover that undergoes little

*Evans, J.R. The Big Weather Book - A Local Forecast Study for Big Delta, Alaska. 7th Weather Group, Air Weather Service USAF, 1957.

loss from either wind or evaporation. Because the snow is so light and fine, a water-equivalent of 20 inches of snow to one inch of water is a reasonably accurate snow-to-water conversion ratio.

Some interesting and potentially useful facts about snow and snowfall at Ft. Greely are summarized as follows:*

1. The most likely hours for snow to fall during mid-winter at Ft. Greely are the early morning hours (0300 to 0800). Rarely is rain, drizzle, or freezing rain experienced in mid-winter.

2. During the three mid-winter months, visibility will be reduced to less than one mile because of falling precipitation less than one-half of one percent of the time.

3. Snow falls on an average of 8.1 days during January, the snowiest month, with total fall averaging 7.2 inches. The average per month snow fall for the months of November, December, and February is between three and four inches.

4. During a ten-year period (1946-1955 inclusive) only one snowfall greater than 6.4 inches was recorded in a 24-hour period and this was less than 10.5 inches. Only 7% of all January snowfalls involved amounts equal to or greater than 1.4 inches.

5. Never during a 10-year period has the depth of snow on the ground exceeded 36 inches. During January, snow depths register between 7 and 12 inches (mean and modal class) 43% of the time. Depths of 2 inches or less prevail 16% of the time on the average from December through February.

f. Ice Fog and Other Restrictions to Visibility

Fog and blowing snow are common causes for reduced visibilities in the Ft. Greely area.** Approximately 90% of the blowing snow moves in the lowest two meters of the atmosphere. In most situations, therefore, horizontal visibility improves at levels above the blowing snow. Since the snow at Ft. Greely is so light and fine, even light winds will produce blowing snow.

*Data taken from. Air Weather Service, Uniform Summary of Surface Weather Observations Parts A and B, Big Delta, Alaska CAA July 1944-June 1955.

**Ice fog was recorded as a restriction to visibility on 347 occasions during 18 Januaries from 1945 through 1962, or about 2½% of all hours. Blowing snow is the second most frequent restriction to visibility, recorded 56 times during the same period.

"Whiteouts" occur during the most severe instances of fog and/or blowing snow. In these situations, light reflectance between the snow cover and hydrometeors is so intense that no shadows appear and visual references are obscured; consequently one loses depth perception and all sense of orientation. During these times, surface and air traffic either comes to a halt or is severely impaired. Artificial illumination is ineffective during whiteouts because of the reflectance factor.

Fogs. Three types of fog can be encountered during the cold weather test season. They are: 1) warm fog consisting of water droplets suspended in the atmosphere at temperatures above 32°F., 2) supercooled (cold) fog consisting of liquid droplets suspended in the air at temperatures below 32°F, and 3) ice fog consisting of minute airborne ice particles.

Warm fog is extremely rare during the cold weather testing season.

Cold or "supercooled" fog occurs when the air temperature is between +32°F and approximately -30°F. This fog can be dispelled either by dry ice seeding from aircraft or by propane seeding from ground-based dispensers.

During periods of supercooled fog, hoarfrost or rime is likely to accumulate on exposed surfaces. If wind is present, the accumulation can be sufficient to break antennas and power lines.

Ice fog not only is the most frequent obstruction to visibility in the winter season, but is also the most significant because of its simultaneity with cold testing temperatures. It consists of microscopic ice crystals which form around smoke particles generated by burning coal and oil and the firing of heavy weapons. Ice fog is a particularly aggravating phenomenon from the point of view of test scheduling because the probability of its formation increases rapidly at temperatures from -25°F to -45°F, limits that also closely describe the most favorable conditions for cold testing. Certain tests are attended by ice fog formations of the tests' own making. For example, the firing of an artillery piece can provide the catalyst needed to trigger the development of a small cloud of ice fog that momentarily engulfs the firing position. Visibility improves shortly thereafter as the scouring action of wind causes the shroud of ice fog to drift to the leeward. To reduce the risk of precipitating ice fog by mechanical means, all running vehicles, generators, and moisture emitting equipment should be moved away from the test area. The test operator can further reduce the chances of fog obscuration by positioning his weapons or vehicles so that the wind can carry the ice particles away from the desired lines of sight. A blower system should be provided if it is absolutely necessary to remove the ice fog that engulfs the test site. Although ice fog is usually man-induced, spontaneous ice fog crystal formation occurs naturally at about the -40°F threshold.

Other restrictions to visibility which can occur at Ft. Greely in the winter are haze and blowing dust during very dry winters.

## III. Climatography of the Ft. Greely Test Area.

### A. Introduction

Climatography can be defined as the geography of climate,--in this case, the geography of climate of the Ft. Greely area. Cold temperature occurrence as well as precipitation and wind patterns have substantial mesoscale variation in a mountain and plains region such as the middle and upper Tanana Valley. Because of this variability, it often is possible to find desirable combinations of atmospheric conditions at sites within the local area to conduct tests that otherwise would have to be moved significant distances to other sites. This section will attempt to predict the variation from place to place in the occurrence rates of these phenomena for several typical synoptic situations. The basis for these predictions is a set of mesoclimatic temperature measurements taken at 24 sites over a three-year period. Figure 8 shows the location of these sites in the Ft. Greely area.

### B. Areal Temperature Patterns During Winter Cold Spells.

Figures 9 and 10 indicate that the distribution of temperatures is largely a reflection of the extent and distribution of the major terrain features of the region, with lower elevations generally colder than higher elevations. Figure 9 shows departure from the minimum temperature at the main weather station located at the airport (FAA Station) when the minima were below -40°F. Minimum temperatures were used to portray the departures rather than simultaneous temperatures read from thermographs because, at the low temperatures involved, it frequently happened that the thermograph clocks failed to operate properly. Ten cold spells were used as a basis for preparing this map. In no case did the mean vary from the median by more than 2 F°. As can be seen, the Delta River lowland, Bolio Lake, and Butch Lake sites normally have minimum temperatures 10 to 15 F° lower than those for the FAA station during the very cold periods. Higher elevations, however, were generally 10 to 15 F° warmer. Figure 10 shows normal variation in the temperature field under conditions of clear skies, light winds, and FAA station temperature between -11°F and -20°F. This map, from Evans, differs from the preceding map in that it shows median differences rather than mean differences, based on simultaneous values at all sites. During these periods, temperature differences at levels both above and below the FAA station are greater than during the very cold spells.

Warm "spots" and cold "spots" appear in arrays on both maps with the cold spots associated with low-lying areas like Bolio Lake, Butch Lake, and the river flats, and the warm spots with domes, hills, rises, and mountains (Donnelly Dome and Granite Mountain). The advisability of camping on higher places during the Arctic winter and the inadvisability of conducting cold soak tests on the rises should be apparent. The air above the cold spots is characterized by a rise in temperature of about 1 F° for each 50 foot increase in elevation as measured along adjacent slopes. This rate does not necessarily hold for all slopes however,

# FORT GREELY AREA - ALASKA

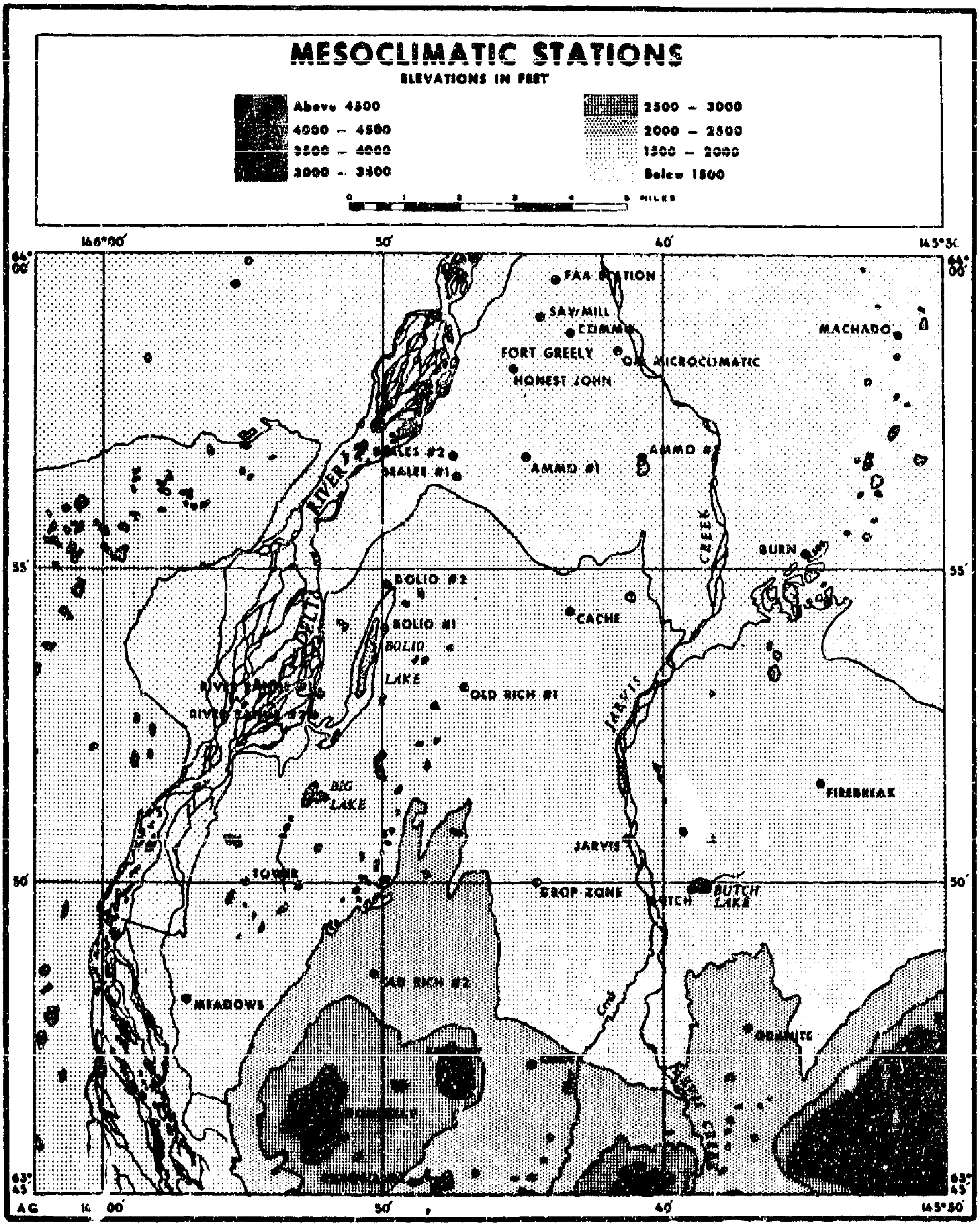
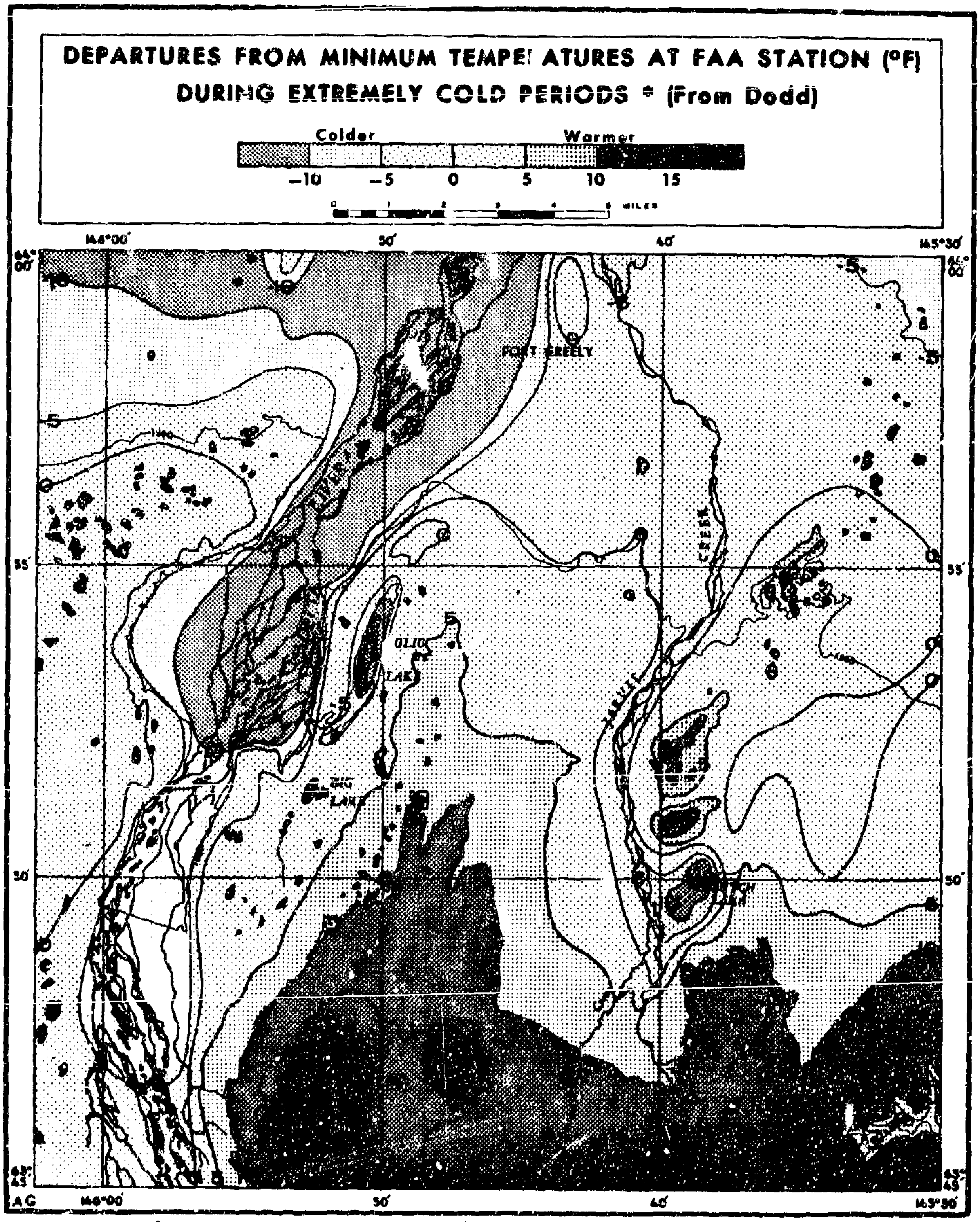



Figure 8

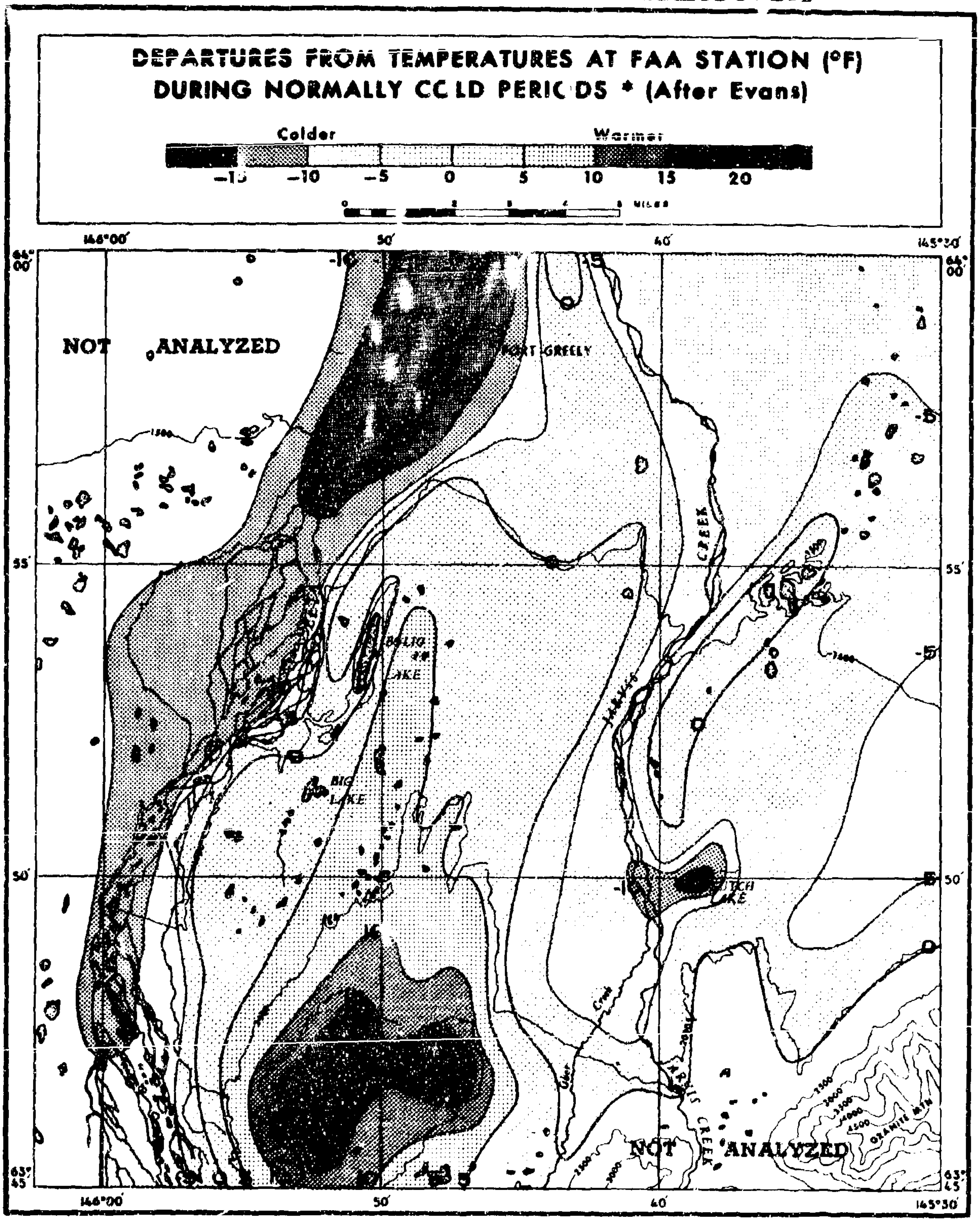
# FORT GREELY AREA - ALASKA




* Minimum temperature below −40°F at Fort Greely

Figure 9

# FORT GREELY AREA - ALASKA




* From −11°F to −20°F as a minimum at Fort Greely

Figure 10

because of special patterns of air drainage associated with each lowland pocket.

There are very large expanses of "normal" areas, i.e., areas for which the temperatures at Ft. Greely itself are representative during cold spells. Year to year variability in the occurrence rates of low temperatures is most noticeable in these areas. Nevertheless, the occurrence rates of adequately low temperatures within these "cold spots" do not meet the needs for cold soak tests at Ft. Greely in some years. It is still "weather" as generated by the passage of cyclonic storms that determines the occurrence of "cold spells" through controlling effects exerted on the development, strength, and persistence of the Arctic inversion. Local winds of cyclonic origin having negative effects on the Arctic inversion are discussed in the following section entitled "wind patterns".

C. Wind Patterns

Figure 11 shows a pattern of wind flow that is highly characteristic of the Ft. Greely area during the winter season. Frequent winter storms in the Gulf of Alaska are the prime cause for this flow pattern. While in the Gulf, the storms tend to cause easterly or southerly surface winds in the interior of Alaska. Yet, even when the isobaric orientation would dictate a southerly flow at Ft. Greely, the wind will blow persistently from the east because of lowered pressures at Big Delta and the orientation of the Alaska Range. In many such instances when winds blow from the east at Ft. Greely, a southerly wind is indicated for Isabel Pass. However, because of the orientation of the pass and the force of the easterly flow through the Tanana Valley, the warmer southerly current misses Ft. Greely. Meanwhile, the high Granite Mountains seem to concentrate the colder easterly current and deflect it into a narrow stream which passes directly over Ft. Greely. According to Ehrlich, this stream varies in width, but it is known to be two miles or less in width as it passes over the Tanana Plains towards Nenana. Winds to the leeward of Donnelly Dome and Granite Mountain are highly unpredictable during these periods because of the convergence of the two streams of air, and because vertical and horizontal turbulence is induced by the two mountain features.

Figure 12 shows the distribution of wind speeds and directions at Ft. Greely for the winter months. During this season winds from the east-southeast, the prevailing direction, persist 36% of the time. Westerly or northwesterly flow can be induced however, at times when the slope of the isobaric gradient is from the west. This wind pattern is established whenever a low-pressure trough initially centered in the Gulf of Alaska moves eastward to an inland position just east of Ft. Greely. Immediately after the storm center passes Ft. Greely, the winds suddenly slacken and shift to the west or northwest. When this situation develops, the mountains which formerly channeled the easterly flow down slope through the Tanana Valley towards Ft. Greely now have less influence because of the upslope motion of the air, the weaker (but reversed) pressure gradient, and less effective containment of the air within the higher mountain valleys.

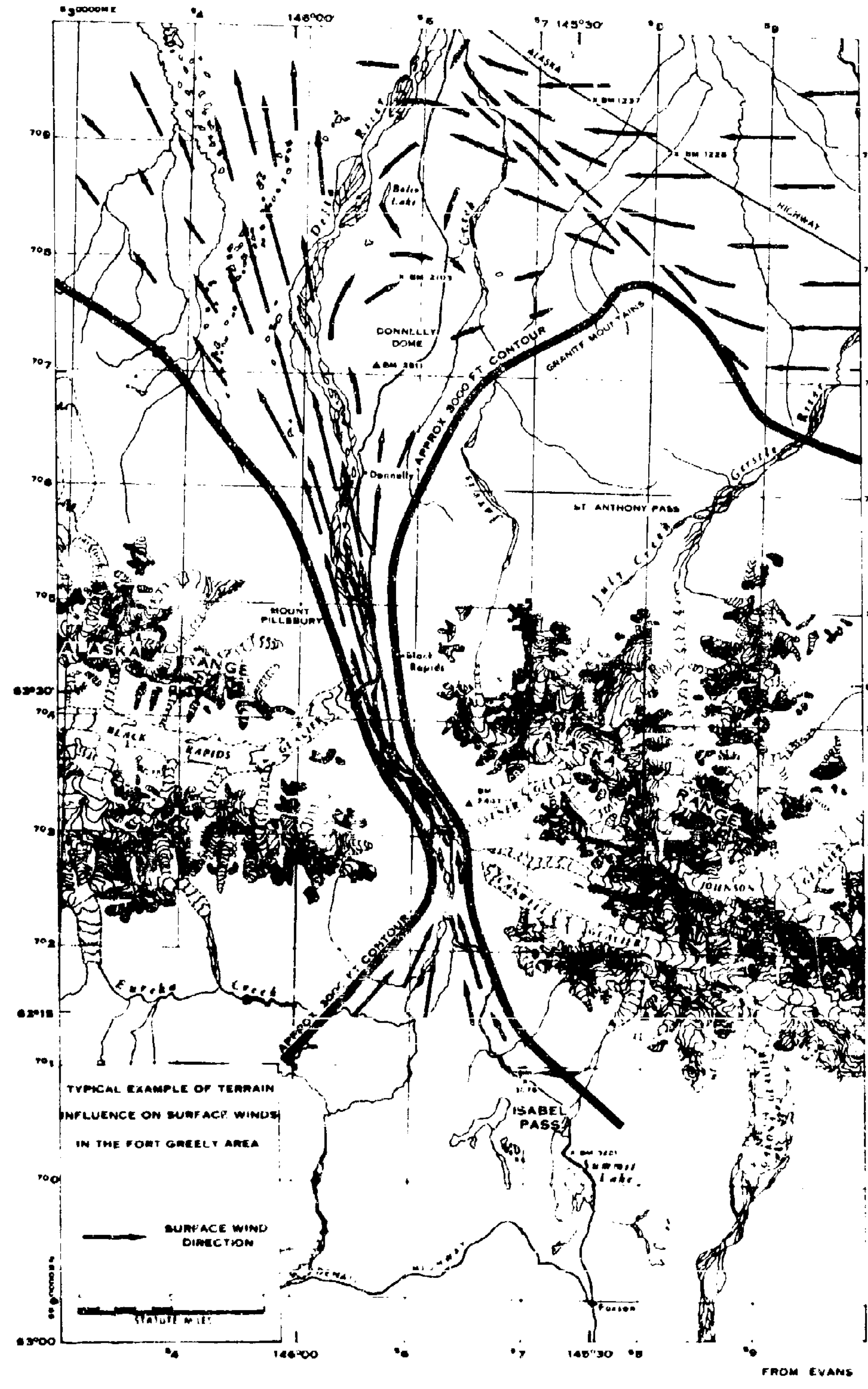
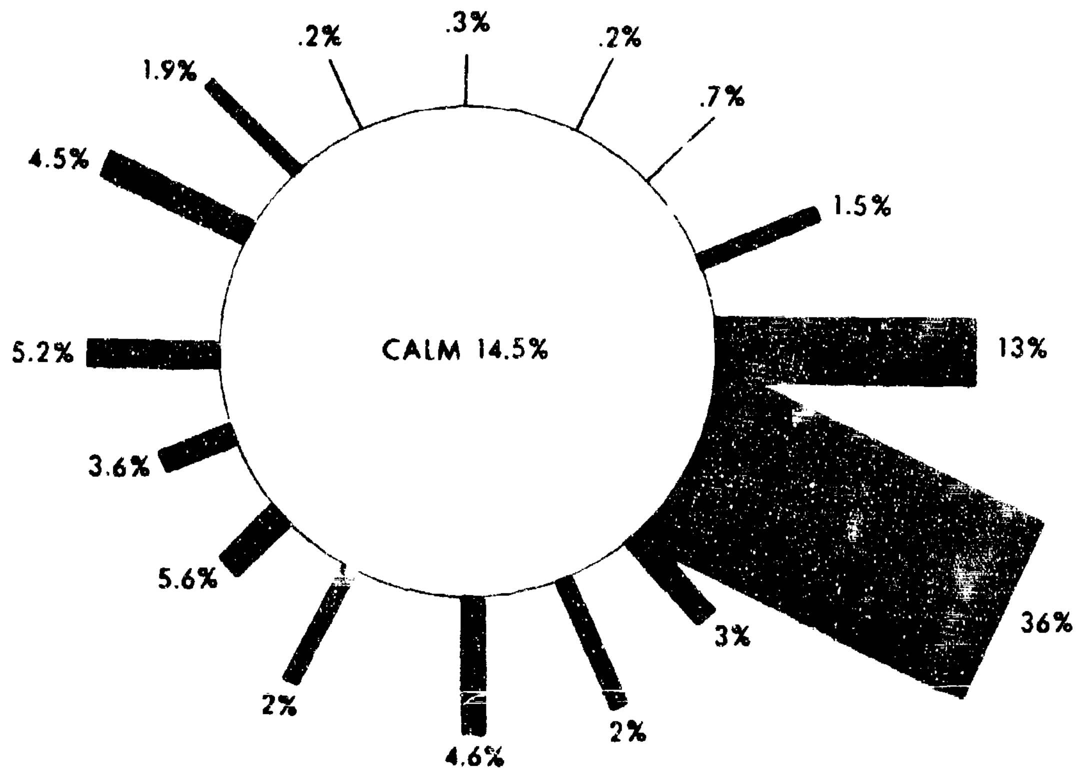

TYPICAL EXAMPLE OF TERRAIN INFLUENCE ON SURFACE WINDS IN THE FORT GREELY AREA
SURFACE WIND DIRECTION
STATUTE MILES
APPROX 3000 FT CONTOUR
GRANITE MOUNTAINS
DONNELLY DOME
Donnelly
ST ANTHONY PASS
MOUNT PILLSBURY
ALASKA RANGE
BLACK RAPIDS GLACIER
ISABEL PASS
Summit Lake
HIGHWAY
146°00'
145°30'
63°30'
63°15'
63°00'
FROM EVANS

**Figure 11**

# SURFACE WIND ROSE BIG DELTA, ALASKA
# DECEMBER - JANUARY - FEBRUARY




23,667 OBSERVATIONS

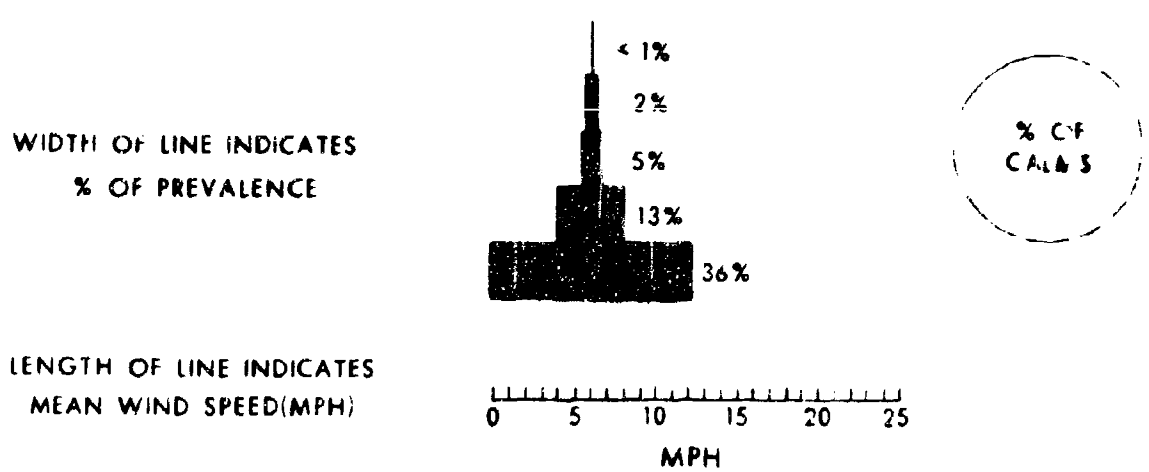



Figure 12

D. Patterns of Snow Accumulation.

The major factors which cause snow in the Ft. Greely area have been discussed in a previous section. Unlike temperature data which are available in quantity for various sites throughout the Ft. Greely area, snow data are extremely scarce for sites other than Ft. Greely itself. Fortunately, the only facet of snow cover that need be stressed here is the tendency for snow to accumulate to greater depths in forested and elevated areas than on the low-lying, wind-swept, interior plains. Because the snow is usually light, it drifts easily, accumulating in places to the leeward of wind barriers such as houses, vehicles, and protruding terrain features. The drifts behind such brakes can be substantial. This characteristic of snow should be taken into account when positioning vehicles and other equipment for tests.

IV. Comparison of the Climate of Ft. Greely with Other Possible Test Locations in Interior Alaska.

A. Introduction

The current lower limits of "Cold" and "Extreme Cold" as specified in AR 70-38 are -50°F and -70°F. The requirement for six continuous hours of -70°F as the design limit of Extreme Cold has rarely been met in Alaska, and it is not reasonable to expect this requirement to be satisfied on a regular basis anywhere within the test area.* The ambient air temperature of -50°F for six hours as the lower limit of Cold conditions is experienced over a wide variety of locations in interior Alaska, including Ft. Greely. It is appropriate, therefore, that as much field testing of materiel designed for cold-weather use be accomplished at or near this temperature as is possible. The comparisons in this section are made to demonstrate the differences in the frequency of occurrence of days with selected low temperatures and days with temperatures above freezing at potential as well as actual testing sites.

B. Meteorological Station Comparisons.

Of the stations compared in Table VI, Big Delta, Richardson, and Black Rapids show the lowest frequencies of -40°F and lower temperatures. These three stations, which might best be described as the warmest stations, are located either within the confines of Ft. Greely itself as is the Big Delta station, or close by without, as are Richardson and Black Rapids. The meso-scale variation of low temperature occurrence between Big Delta and other sites within Ft. Greely has already been discussed in Section III. It should be remembered however, that both colder and warmer sites can be found nearby.

*It should be noted that a low temperature of -70°F was recorded at Tok on two successive days -- 13 and 14 Dec., 1964. However, the data are insufficient to determine whether this low level of temperature prevailed for six continuous hours or not.

A

TABLE VI: INCIDENCE OF TEST-CRITICAL TEMPERA[illegible]RES DUR[illegible]
FOR SELECTED STATIONS [illegible] INTERI[illegible]

| STATION | LOCATION | PERIOD OF RECORD | %PROBABILITY FOR INCURRING MAXIMUM AND MINIMUM TEMPERATURES BELOW AND ABOVE DESIGNATED VALUES ON ANY WINTER DAY. | | | | | | | | % [illegible]ROBABI[illegible]Y I[illegible]M AND [illegible] B[illegible]OW AND [illegible] O[illegible] ONE OR [illegible] M[illegible]TH. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ≤-40°F | | ≤-50°F | | ≤-60°F | | ≥+32°F | | ≤ 4[illegible]°F | | ≤ [illegible] |
| | | | MAX | MIN | MAX | MIN | MAX | MIN | MAX | MIN | M[illegible] | MIN | M[illegible] |
| ALLAKAKET | 66°34'N 152°44'W | 1935-1954 | * | 32 | * | 17 | * | 5 | * | 0 | * | 95 | * |
| FORT YUKON | 66°35'N 145°18'W | 1935-1954 | 8 | 28 | 4 | 15 | 0.5 | 5 | 0.5 | 0 | [illegible] | 92 | 2[illegible] |
| NORTHWAY | 62°58'N 141°58'W | 1942-1954 | 5 | 20 | 1 | 11 | 0 | 2 | 2 | 0 | [illegible] | 67 | 2[illegible] |
| FAIRBANKS | 64°58'N 147°f2'W | 1935-1954 | 3 | 12 | 0.5 | 4 | 0 | 0 | 7 | 0.1 | [illegible] | 63 | 7 |
| BIG DELTA | 64°00'N 145°44'W | 1942-1954 | 0.6 | 11 | 0.1 | 3 | 0 | 0.6 | 9 | 0.6 | [illegible] | 61 | 3 |
| RICHARDSON | 64°17'N 146°22'W | 1935-1942 | 1 | 7 | 0 | 1 | 0 | 0 | 15 | 0.8 | 1[illegible] | 57 | 0 |
| BLACK RAPIDS | 63°32'N 145°51'W | 1935-1942 | 0 | 0.7 | 0 | 0 | 0 | 0 | 34 | 2 | [illegible] | 17 | 0 |

*Data Incomplete

ST-CRITICAL TEMPERATURES DURING WINTER (DEC., JAN., FEB.)
: SELECTED STATIONS OF INTERIOR ALASKA

| URRING MAX- PERATURES GNATED VALUES | | | | % PROBABILITY FOR INCURRING MAXIMUM AND MINIMUM TEMPERATURES BELOW AND ABOVE DESIGNATED VALUES ON ONE OR MORE DAYS OF ANY WINTER MONTH. | | | | | | | | % PROBABILITY FOR INCURRING MAXIMUM AND MINIMUM TEMPERATURES BELOW AND ABOVE DESIGNATED VALUES ON ONE OR MORE DAYS OF ANY WINTER SEASON. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -60°F | | ≥ +32°F | | ≤ -40°F | | ≤ -50°F | | ≤ -60°F | | ≥ +32°F | | ≤ -40°F | | ≤ -50°F | | ≤ -60°F | | ≥ +32°F | |
| X | MIN | MAX | MIN | MAX | MIN | MAX | MIN | MAX | MIN | MAX | MIN | MAX | MIN | MAX | MIN | MAX | MIN | MAX | MIN |
| | 5 | * | 0 | * | 95 | * | 79 | * | 27 | * | 0 | * | 100 | * | 100 | * | 68 | * | 0 |
| .5 | 5 | 0.5 | 0 | 38 | 92 | 23 | 65 | 6 | 33 | 13 | 0 | 78 | 100 | 56 | 94 | 17 | 61 | 17 | 0 |
| | 2 | 2 | 0 | 36 | 67 | 22 | 47 | 0 | 19 | 17 | 0 | 75 | 92 | 42 | 67 | 0 | 33 | 50 | 0 |
| | 0 | 7 | 0.1 | 18 | 63 | 7 | 26 | 0 | 0 | 56 | 4 | 58 | 83 | 16 | 58 | 0 | 0 | 95 | 11 |
| | 0.6 | 9 | 0.6 | 8 | 61 | 3 | 25 | 0 | 3 | 58 | 8 | 17 | 83 | 8 | 50 | 0 | 8 | 83 | 25 |
| | 0 | 15 | 0.8 | 10 | 57 | 0 | 5 | 0 | 0 | 86 | 14 | 29 | 100 | 0 | 14 | 0 | 0 | 100 | 43 |
| | 0 | 34 | 2 | 0 | 17 | 0 | 0 | 0 | 0 | 89 | 50 | 0 | 17 | 0 | 0 | 0 | 0 | 100 | 83 |

**Black Rapids**, the warmest of the seven locations, is located just south of several of Ft. Greely's courses and ranges and is the site of the Northern Warfare Training Center. It is representative of the area down valley from Isabel Pass where temperatures are frequently moderated by the warm winds of the chinook. Courses like Donnelly Loop and ranges like A.D. Range and Field Firing Range are also influenced by chinook winds as they descend the Delta River Valley.

**Richardson**, located immediately downstream from Ft. Greely/Big Delta in the Tanana Valley is representative of many sites within the northwestern confines of Ft. Greely and neighboring districts. It is somewhat warmer than Big Delta because it is slightly more exposed to the warming effects of the winds that sometimes sweep over the area. (see Figure 11).

Fairbanks is located 105 miles down valley from Big Delta/Ft. Greely and is considered representative of the area immediately surrounding Fort Wainwright. Facilities available at Fort Wainwright are sometimes used for cold weather testing purposes. Table VI shows that Fairbanks experiences deep cold quite often and is less susceptible to the warming influences of the Chinook winds than is Big Delta.

Northway, in its position upstream from Ft. Greely within the Tanana Valley, lies just beyond the effective range of the warming downslope winds from Isabel Pass. Northway is sometimes used as a site for cold tests whenever prospects for severe cold are more promising than at Ft. Greely. The percent occurrence of -40°F and lower temperatures is higher than at Ft. Greely and Ft. Wainwright, but even so, probabilities for occurrence on any one winter day are still relatively low.

Ft. Yukon and Allakaket are both located within the Arctic Circle on major rivers in lowland pockets of interior Alaska. Both sites are significantly colder than Ft. Greely in winter and represent a potential cold weather testing resource for the Arctic Test Center. However, a special study should be made to determine the "best" site; such a study should consider environmental factors other than low temperatures, and include cost evaluations. Neither site is well served by highways though the Elliot and Steese Highways out of Fairbanks have been completed portions of the way toward both.

The last two columns of each section of Table VI show probabilities for above freezing temperatures during winter for each of the seven stations studied. Since these periods of thaw can begin suddenly, with time of onset coinciding with the arrival of the Chinook winds, they produce a kind of natural temperature shock, if occurring during tests, that can effect materiel deleteriously. In addition, courses and roads become impassable, lubricants must be changed in vehicles, and food stores thaw, to mention a few resultant problems that must be contended with.

Extremely disruptive to tests also is the sudden replacement of the warm air (Chinook flow) by frigid Arctic air following passage of a cold front at the test site. Though the probability for this chain of events to happen is low, its occurrence during tests can cause windshields to crack, water and mud in moving mechanical parts to quick-freeze, and frost to form quickly on sensitive instruments.

## V. Surface Conditions

### A. Drifting Snow

Snow accumulation is a detrimental factor that must be reckoned with during the Ft. Greely winters. Because drifting snow consists of flakes that are very light, fine, and dry, it does not compact easily once settled on the ground. The slightest wind causes the loose-lying snow to become airborne with drifts forming in places favoring accumulation. Much can be done however to minimize the negative effects of drifting snow.

#### 1. Effects on Construction and Countermeasures

Should building construction be contemplated at a test site, a study of the immediate area should be made prior to undertaking the project to determine the climatological and other environmental factors likely to effect snow deposition. Of particular concern is the total snowfall, the directions of the prevailing winds, the direction of the snow-bearing winds, the frequency and duration of storms, and the natural obstacles to wind flow at the site.

Although the actual positioning of a building in relation to wind direction is a controversial subject, it is generally considered good practice to orient the building such that its long axis is normal to the prevailing wind. The practice is especially effective when a space is left between the snow surface and the floor of a building (or storage platform). This arrangement will permit entrances at the ends of the building to remain open for maximum periods of time. Rear entrances, though accessible for a time become drifted shut sooner than side entrances. In situations involving heavy drifting, it may be necessary to dig entrance ramps through the drifts to gain access to the building (or under snow structure). Such trenches should parallel the prevailing winds so that they open downwind.

In cases of two or more structures, site selections should be made with consideration for ample space between buildings as well as alignment in rows normal to the wind. If alignment is impossible, the buildings should be spaced at sufficient distances apart to prevent one from causing drifts to form against another (i.e., a minimum allowance of 200 feet for one-story buildings and correspondingly more for multi-story buildings - a good rule of thumb to apply in determining distance apart is 25 times the height of the highest building).

The useful life of buildings may be extended by constructing them on piles. This allows the wind to sweep under the buildings, keeping these areas, and those immediately downwind, free of drifted snow. For most buildings an unobstructed space of three to five feet beneath the structure is sufficient.

2. Surface Maintenance.

It is generally advisable to maintain a smooth and hard snow cover in those sections of the test site subject to hard usage by men and equipment. One system being used successfully involves breaking up the snow crust with a drag made of heavy timbers, after which a roller of large diameter is drawn over the snow to pack and smooth the surface. This treatment eliminates surface obstructions and leaves few places for drifting snow to accumulate.

3. Vehicle Storage.

Vehicles should be parked where they will not cause drifts to form around other vehicles or buildings. This is best accomplished by placing them in rows aligned with the wind and well to one side of the test area. At times it may be more convenient to park them downwind of the test area, in which case it is best to leave a distance of 200 to 300 feet between the test area and the parked vehicles.

4. Materials Storage.

Several methods for open storage of materials are recommended:

a. Raised Pads. These usually are constructed as platforms made of heavy planks supported at their ends by empty oil drums. The platforms are spaced about 10 feet apart in rows normal to the wind. The width of a platform can be altered by varying the number of oil drums used; it is customary however, to use three or four lined up one behind another and parallel with the wind. For convenience and easier access, it is better to lengthen the raised pads than to widen them.

Material will probably have to be relocated two or three times during each winter season. Because the wind will usually keep the areas under the platforms swept clear of snow, access to the stored material is generally good and the moves can be made easily.

b. Surface Storage. Two methods for the storage of material on snow surfaces are suggested. First, a wooden "V" or 1/2" or 3/8" plywood can be constructed and installed on the snow surface with the apex pointing into the wind. This can be done with 8-ft. plywood sheets placed on end, two or three panels on each side. The material to be stored should be piled as compactly as possible and should press against the plywood to its top. If this is done properly, no anchoring is needed.

This system not only protects the material from the drifting snow, but also provides easy access from the rear. One such installation was effective for a period of about 14 months at Camp Century, Greenland.

The second method involves storage in a single compact pile, the profile of which should be kept low and as even as possible. Each corner of the storage pile should be marked with a bamboo pole. Drifting snow will soon fill in the interspaces between units of the pile and form banks against the outer sides; however, accumulations will not get higher than the highest box or crate. Very large boxes may be stored singly and will be scoured clean for a while, but they should be moved when the snow begins to pile up around the sides.

5. Use of Snow Fences.

Some problems associated with drifting snow can be alleviated by the proper use of snow fences, of which there are three basic types: collectors, which brake the winds to speeds incapable of sustaining the snow particles aloft; leaders, which change the direction of the drifting snow and cause it to be blown past the object to be protected; and blowers, which cause the windspeed to increase over a specified area and thus keep it blown clear of snow.

The type of fence needed will depend upon its proposed use since no two drift problems are exactly the same. However, during the past 150 years, many aspects of snow drifting have been studied and various techniques for fencing tried. As a result standard methods for installing fences have evolved. Such measures are commonly employed in the protection of highways and railroads, particularly in areas having seasonal snow covers.

The most commonly used snow fence is the vertically-slatted, wood-and-wire type which comes in lengths of 50 or 100 feet, and in heights of 18 to 48 inches. It has a density ration (solid area) of about 42%. It should be erected on steel posts along a line at right angles to the snow-bearing wind with its bottom raised for maximum catch about 6-10 inches above the ground surface. It should be positioned 150 to 200 feet upwind of the area to be protected (see Figure 12 for prevailing wind patterns). The fence posts should be erected before the ground freezes in the fall.

Solid "V" deflector-type fences, similar to those described for storage protection, can be used to keep snow out of trenches and entrance ramps. As the snow accumulates, additional plywood can be added to increase the height of the fence.

If plywood is not available, such materials as snow blocks, empty oil drums, or lumber can be used to improvise various forms of protection.

6. Use of Snow Removal Equipment

No matter what preventive measures are taken, snow still tends to accumulate in critical places. To remove such accumulations, snow removal equipment should be available for immediate use. Probably the most useful piece of equipment for small scale snow removal, except for the hand shovel, is the front-loader tracked vehicle (Traxcavator) with interchangeable bucket and blade.

For massive snow moving, or road maintenance, the low ground pressure (LGP) bulldozer is perhaps the best; however, it has the disadvantage of being unable to maneuver effectively in small areas.

In removing snow from areas that must be kept clear, it is important that no ridges of snow be left on the upwind side of plowed areas unless additional drifting can be tolerated.

B. River and Lake Ice

1. River Ice

The ice which forms on rivers has the same basic characteristics as lake ice. In given situations however, the surface condition of river ice can be quite different than that of lake ice. It sometimes happens that the original ice surface that forms on a river is broken up during spells of warm weather, high winds, and rain. Upon refreezing, the new surface can be very rough, a condition that sometimes remains for the balance of the winter.

The rivers of the Ft. Greely area, the Delta River and Jarvis Creek, consist mainly of a series of braided channels that freeze over early, making possible their use as vehicle crossways throughout the winter. Generally the shallow channel waters of Jarvis Creek freeze over completely with ice thicknesses reaching to the bottom. Here, no traversing problems are encountered. However, certain channel sections remain ice-free due to the influx of ground water thereby preventing their use as traverses.

Portions of the Delta River from Redeye to a point a few miles south of Donnelly Dome remain open due to the influx of warm ground water. In these sections, ice crossings are impossible. However, the area from Sawmill Range to the Tanana River freezes over completely to form a solid road bed useful as a crossing. Other parts of the Delta River, such as Black Rapids, have channels with very rapidly flowing water. These sections usually freeze over approximately one month later than areas where the water is moving slowly. The freeze-over date of the Black Rapids section for the 1966-67 winter season was 19 November 1966. The rivers in the Ft. Greely area, except where extremely rapid water is flowing, can usually be expected to freeze over between 19 and 29 October. Maximum ice thicknesses vary from 30 to 45 inches depending on air temperature and snowfall.

2. Lake Ice

The lake located in the Ft. Greely area freezes over about the first of November, give or take 10 days or so. The maximum ice thickness which is reached just prior to break up, varies from 32 to 38 inches, depending on air temperature and snowfall. If there is little or no snowfall, the ice appears to be black in color and has good transparency. The growth rate of the ice depends primarily on the snow cover. In general, the ice thickness varies inversely with the depth of the snow cover. If the snowfall if heavy, snow ice usually forms. This happens when the weight of the snow cover depresses the ice until the ice cracks or fails. Water then wells up through the cracks, saturates the snow cover, and forms slush. This slush layer freezes from the top downward with the newly formed ice appearing whitish in color, the result of air bubble entrapment. At this stage there is a layer of slush and water between the new ice and the original clear ice. Trafficability is very poor during this time. In the spring the ice becomes soft and weak. It is advisable to curtail all operations on the ice by the time the surface snow disappears. Table VII shows load-bearing capacities for ice at various thicknesses for selected vehicles and aircraft.

C. Ground Conditions

1. Composition of the Surface Layer

The Fort Greely area is underlain by glacial moraine and broad, flat, gravelly outwash plains. These glacial deposits are relatively coarse, sandy, and have the characteristics of high permeability and good bearing strength.*

Both Alluvial and aeolian deposits of sand and silt in layers of varying thicknesses overlie the glacial materials in many places. Areas of muskeg are generally associated with all poorly drained depressions. These fine-grained organic and mineral soils, if sufficiently developed, are troublesome to ground traffic during the entire thaw season. Travel over muskeg areas is most difficult shortly after freeze-up when only the upper surface is frozen.

2. Frozen Ground

The Ft. Greely area is located in the discontinuous permafrost zone of Alaska.** Permafrost, which is a permanently frozen layer of soil or bedrock, is fairly deep beneath most of the glacial deposits,

*Holmes, G.W., and W.S. Benninghoff (1957). Terrain Study of the Army Test Area, Ft. Greely, Alaska, Mil. Geol. Br., USGS, Wash. D.C., Vol. 1., 287 pp (Based on the Casagrande system.)

**Ferrians, O.J., (1965). Permafrost Map of Alaska, USGS Misc. Geologic Investigation Map.

## TABLE VII

### Load-Bearing Capacity of Fresh-Water Ice

| | Min. Ice Thickness (in.) | Min. Distance between Units (ft.) | (m.) |
|---|---|---|---|
| Men | 2 | 15 | 5 |
| **Vehicles** | | | |
| 1/4-ton truck | 8 | 50 | 15 |
| 3/4-ton truck | 10 | 65 | 20 |
| 2-1/2 ton truck | 16 | 80 | 25 |
| 5-ton truck | 22 | 200 | 60 |
| 5-ton tractor w/loaded trailer | 36 | 260 | 75 |
| M561 Cargo carrier | 10 | 65 | 20 |
| M8A1 tractor | 26 | 230 | 70 |
| M41A1 tank | 26 | 200 | 60 |
| M48A2 tank | 32 | 230 | 70 |
| M60 tank | 32 | 230 | 70 |
| M108 Howitzer, SP, 105 mm | 20 | 130 | 40 |
| M88 tank recovery vehicle | 34 | 230 | 70 |
| M109 Howitzer, SP, 155 mm | 20 | 130 | 40 |
| M110 Howitzer, SP, 8 mm | 22 | 165 | 50 |
| M113 APC | 18 | 80 | 25 |
| M114 armored carrier | 16 | 65 | 20 |
| M116 cargo carrier | 14 | 50 | 15 |
| M578 recovery vehicle | 26 | 200 | 60 |
| Tractor, D7, Std. | 20 | 130 | 40 |
| Tractor, D8, Std. | 24 | 165 | 50 |
| Crane, 20 ton | 24 | 230 | 70 |
| Grader | 16 | 165 | 50 |
| M-6 transporter, rolling liquid | 10 | N/A | |
| **Aircraft** | | | |
| O-1A, E | 8 | 30 | 10 |
| OV-1A, B, C, | 18 | 65 | 20 |
| U-1A | 10 | 65 | 20 |
| U-6A | 10 | 50 | 15 |
| U-8D, F | 10 | 65 | 20 |
| CV-2A | 20 | 180 | 55 |
| CV-7A | 20 | 200 | 60 |
| OH-13H | 8 | 30 | 10 |
| OH-23D | 8 | 30 | 10 |
| UH-1A, B, D, | 10 | 65 | 20 |
| UH-19D | 12 | 65 | 20 |
| CH-21C | 14 | 80 | 25 |
| CH-34C | 13 | 80 | 25 |
| CH-37B | 20 | 200 | 60 |
| CH-47A | 20 | 200 | 60 |

particularly in the outwash where the top of the permafrost is at least 25 feet from the surface. In bog areas or in areas where silt is more than three feet thick, permafrost may be within two to four feet of the surface. Problems associated with mineral terrain are minimal in winter when soils are usually frozen at least three to 10 feet in depth. Some difficulty with vehicle operations may be expected early in the freezing season when the surfaces of the bogs or shallow ponds, frozen only to shallow depths, are concealed by a thin snow cover. These situations can be partially avoided by limiting operations to ridges, particularly in areas of obvious depressions.

Ground temperature information is limited, although some data are available from the Big Delta Airport.* The average freezing season as computed from statistics for years between 1947-1954 begins on 14 October and ends on the 22nd of April. Ground temperatures in what appears to be outwash (sandy silt-gravelly sand) indicate an average depth of frost penetration during winter of 14 feet for the years 1947 to 1960. The maximum and minimum temperatures for the same years at a depth of 23 feet were 37°F and 30.5°F, respectively.

The ground temperatures vary greatly depending on moisture content of the ground, soil texture, and vegetation cover. If prediction of depth of freeze or thaw were required for a particular area where ground conditions are known, the values could be calculated by using USA TM 5-852-6. Information on freezing and thawing indices has been compiled by Fulwider, 1968 (Table VIII).

*Aitken, G.W. (1964). Ground Temperature Observations, Big Delta, Alaska. US Army Materiel Command, Cold Regions Research and Engineering Lab., Tech. Report 104, 15 pp.

# TABLE VIII

## FREEZING & THAWING INDICES

## Big Delta (FAA), Alaska

| DATES Beginning | DATES Ending | FREEZING INDEX (°F-days) | THAWING INDEX (°F-days) |
|---|---|---|---|
| 20 Oct 1946 | 20 Apr 1947 | 5276 | |
| 21 Apr 1947 | 9 Oct 1947 | | 3010 |
| 10 Oct 1947 | 5 May 1948 | 4385 | |
| 6 May 1948 | 11 Oct 1948 | | 2756 |
| 12 Oct 1948 | 5 May 1949 | 5292 | |
| 6 May 1949 | 2 Oct 1949 | | 2914 |
| 3 Oct 1949 | 14 Apr 1950 | 5002 | |
| 15 Apr 1950 | 6 Oct 1950 | | 3498 |
| 7 Oct 1950 | 13 Apr 1951 | 5769 | |
| 14 Apr 1951 | 27 Sep 1951 | | 3504 |
| 28 Sep 1951 | 14 Apr 1952 | 5196 | |
| 15 Apr 1952 | 16 Oct 1952 | | 2924 |
| 17 Oct 1952 | 15 Apr 1953 | 3882 | |
| 16 Apr 1953 | 14 Oct 1953 | | 3664 |
| 15 Oct 1953 | 21 Apr 1954 | 5076 | |
| 22 Apr 1954 | 3 Nov 1954 | | 3226 |
| 4 Nov 1954 | 26 Apr 1955 | 4595 | |
| 27 Apr 1955 | 5 Oct 1955 | | 2365 |
| 6 Oct 1955 | 8 Apr 1956 | 6161 | |
| 9 Apr 1956 | 19 Sep 1956 | | 3324 |
| 20 Sep 1956 | 11 Apr 1957 | 5117 | |
| 12 Apr 1957 | 24 Sep 1957 | | 3533 |
| 25 Sep 1957 | 30 Mar 1958 | 3825 | |
| 31 Mar 1958 | 2 Oct 1958 | | 3618 |
| 3 Oct 1958 | 22 Apr 1959 | 5582 | |
| 23 Apr 1959 | 5 Oct 1959 | | 3024 |
| 6 Oct 1959 | 21 Apr 1960 | 4523 | |
| 22 Apr 1960 | 4 Oct 1960 | | 3203 |
| 5 Oct 1960 | 21 Apr 1961 | 4531 | |
| 22 Apr 1961 | 4 Oct 1961 | | 3093 |
| 5 Oct 1961 | 16 Apr 1962 | 5505 | |
| 17 Apr 1962 | 9 Oct 1962 | | 3029 |
| 10 Oct 1962 | 20 Apr 1963 | 4296 | |
| 21 Apr 1963 | 8 Oct 1963 | | 3189 |
| 9 Oct 1963 | 11 May 1964 | 5008 | |
| 12 May 1964 | 13 Oct 1964 | | 2944 |
| 14 Oct 1964 | 23 Apr 1965 | 4958 | |
| 24 Apr 1965 | 27 Sep 1965 | | 3036 |
| 25 Sep 1965 | 26 Apr 1966 | 5810 | |
| 27 Apr 1966 | 6 Oct 1966 | | 3147 |



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TABLE VIII (Cont'd)

| | | |
|---|---|---|
| Avg. 1947-1956 (10 years) | 5063 | 3168 |
| Avg. 1957-1966 (10 years) | 4916 | 3180 |
| Avg. 1947-1966 (20 years) | 4990 | 3174 |

**Avg. date begin of freeze:** 1947-1956, 11 Oct; 1957-1966, 2 Oct; 1947-1966, 6 Oct.

**Avg. length of freeze days:** 1947-1956, 190; 1957-66, 199; 1947-66, 195.

**Avg. date begin thaw:** 1947-1956, 19 Apr; 1957-1966, 19 Apr; 1947-1966, 19 Apr.

**Avg. length of thaw days:** 1947-1956, 175; 1957-1966, 166; 1947-1966, 170.

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2. Aitken, G.W., Ground Temperature Observations, Big Delta, Alaska, US Army Materiel Command, Cold Regions Research and Engineering Lab., Technical Report 104, 1964.

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4. Dodd, A.V. Mesoclimatic Temperature Differences in the Fort Greely, Alaska Area. QM Research and Engineering Center, Natick, Mass. Earth Sciences Division Technical Report ES-3, April 1962.

5. Ehrlich, A., Note on Local Winds Near Big Delta, Alaska, Bulletin of the American Meteorological Society, 34: 181-82 (April 1953).

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7. Holmes, G.W. and W.S. Benninghoff, Terrain Study of the Army Test Area, Ft. Greely, Alaska Vol 1. Military Geology branch, USGS, Wash., D.C., 1957.

8. Mitchell, J.M., Strong Surface Winds at Big Delta, Alaska--An Example of Orographic Influence on Local Weather, Monthly Weather Review 84: p. 19 (Jan. 1956).

# APPENDIX A

## Test Site Meteorological Observations

Meteorological observations at Army test sites are ordinarily taken by meteorological teams supplied by the Meteorological Center at Fort Huachuca, Arizona. In certain situations however, such teams cannot be made available, and the test team itself must provide the man-power to carry out the observing function. With this in mind, the following material is offered as elemental instruction on the operation and care of instruments used to take and record meteorological observations at test sites in support of testing activities.

a. Instrument Requirements

(1) Instrument Shelter (Stevenson Screen) USWB Spec 450.0615

(2) Rain and Snow, Gage, USWB Spec 450.2301

(3) Windshield, Alter Type, USWB Spec 450.2151

(4) Thermometer, Standard 10-1/2", USWB Spec 450.1016

(5) Thermometers, max/min, with Townsend Support, USWB Spec 450.1016

(6) Hygrothermograph, USWB Spec 450.8202

(7) Psychrometer, Sling, USWB Spec 450.1016

(8) Anemometer, Totalizing, Robinson 3-Cup.

Optional Items

(1) Microbarograph, USWB Spec 450.7221

(2) Radiation Measurement Equipment

b. Observations

Observations are generally taken and recorded once every 24 hours at approximately the same time of day. More frequent observations can be taken if more detailed information is required. The Hygrothermograph produces a continuous record of temperature and humidity.

(1) Temperature. The ambient air temperature is indicated on the standard USWB 10-1/2" thermometer mounted in the weather shelter. The maximum and minimum temperatures occurrrng within a 24-hour period are indicated by the max/min thermometers also mounted in the weather shelter.

The maximum thermometer is a mercurial thermometer with a constriction in the bore near the bulb to prevent the mercury from withdrawing into the bulb as the temperature falls.

To read the maximum thermometer, release the catch on the support and lower the bulb end slowly until the thermometer is approximately vertical and the mercury column is resting on the constriction at the base. The instrument is then read in the same fashion as a dry-bulb thermometer.

Before setting the maximum thermometer, be sure that the mercury column is resting on the constriction at the base. Otherwise, the glass forming the constriction may be broken when the thermometer is spun. To set it, spin the thermometer until its reading is the same as that of the dry-bulb temperature. If the readings of the dry-bulb and maximum thermometer disagree, check the thermometers for the source of error in accordance with maintenance instructions. Lock the thermometer in place on the support. Reset the maximum thermometer after each observation.

If the maximum thermometer is broken or the reading is known to be in error, obtain the maximum temperature to the nearest whole degree from the hygrothermograph.

Alcohol is used in the minimum thermometer and a freely moving dark-colored glass index is contained in the bore. As the temperature falls, the retreating upper end of the alcohol column retracts the index, which remains at the position of the lowest temperature until reset.

The minimum temperature thermometer is read at the end of the colored glass index farther from the bulb. It should be read without moving it from its correct exposure position and always before reading the maximum thermometer. The minimum thermometer is set after the maximum theremometer has been set by turning it to a vertical position and holding it bulb end up until the index reaches the end of the alcohol column and the reading is the same as the dry-bulb temperature. If the readings of the minimum and dry-bulb thermometers disagree, check the thermometers for the possible source of error (see next paragraph). Reset the minimum thermometer at each observation.

Minimum thermometers are subject to errors caused by separation of the spirit column. Sometimes the spirit vapor condenses in the upper end of the bore to form one or two short segments above the rest of the column. At other times bubbles that form in the column may trap the index. Erroneous readings will result in both cases, and therefore the thermometer should be examined at each observation for separation of the column. Errors also result from recession of the index owing to the shelter's being jarred or subjected to vibration by the wind.

If the minimum thermometer is broken or the reading is known to be erroneous, obtain the minimum temperature to the nearest whole degree from the hygrothermograph.

(2) Precipitation. Precipitation is measured with a standard 8" Weather Bureau rain and snow gage. This gage consists of an outer tube, inner tube and collecting funnel. Only the outer is required for snow measurement. It is essential that the Alter type windshield be used for snow collection. The snow collection should be melted and the water poured into the inner tube and the measurement made with the standard WB measuring stick. This observation gives the water equivalent of the snowfall; the density of the snowfall will be discussed in another section.

The amount of snowfall for the reporting period is measured by placing a clean board in a well-exposed area and measuring the depth of the snow on the board. The board is cleaned and reset on the surface for the next observation. During periods of high winds this observation is erroneous and the amount of snowfall must be estimated.

(3) Humidity. In order to determine humidity, it is first necessary to read both the dry-bulb and wet-bulb thermometers (psychrometer). The dry-bulb thermometer is read as follows. Stand as far from the thermometer as is consistent with accurate reading to prevent body heat from affecting the instrument. Insure that the line of sight from the eye to the top of the liquid column makes an angle of 90° with the thermometer tube. This will avoid making a common reading mistake called the error of parallax. Read the thermometer to the nearest 0.1°. A degree interval begins at the middle of the degree markings etched on the tube.

In driving rain or snow, dry the bulb and shield it from precipitation as long as necessary to permit dissipation of extraneous heat before reading it again. When frost forms on the thermometer, remove it with a warm cloth and allow sufficient time for the dissipation of extraneous heat before reading the thermometer.

To read the wet-bulb thermometer it is first necessary to moisten the bulb with clean water just prior to ventilating the psychrometer (even though the humidity is high or the wick already appears wet). If, however, the temperature is high and the relative humidity is low, or if it is expected that the final temperature of the wet-bulb will be 32°F or less, moisten the wet-bulb thoroughly several minutes before taking a reading so that a drop of water will have formed on the end of the bulb. This will reduce the temperature of the wet-bulb without danger of the wick drying out before the temperature reaches its lowest point. At dry-bulb temperatures below -35°F, do not read the wet-bulb thermometer.

In areas where the temperature is high and the humidity low, use precooled water for moistening the wet-bulb to avert premature drying of the wick. Water can be precooled for this purpose by storing it in a porous jug. To avoid altering moisture conditions in the shelter, do not keep this jug in the shelter. If this method should not be effective, extend the wick and stand the wet-bulb thermometer in an open container of water. This will keep the end of the wick immersed between observations. When the psychrometer is ventilated, remove the wick from the water until the wet-bulb has been read. Regardless of the method used, ventilate the psychrometer in accordance with directions given in the following paragraph on ventilation. If the wick is not frozen and the wet-bulb temperature is below 32°F, touch the wick with clean ice, snow or other cold object to induce freezing.

At dry-bulb temperatures of 37°F or below, use water that has been kept at room temperature in order to melt any accumulation of ice on the wet-bulb. Moisten the bulb thoroughly, at least 15 minutes before ventilating the psychrometer, to permit the latent heat released as the water freezes, to be dissipated before ventilation is begun. Do not allow excess water to remain on the wet bulb, since a thin, thoroughly cooled coating is necessary for good results. Ventilate the psychrometer by whirling for about ten seconds. Then quickly read both wet-bulb and dry-bulb thermometers, wet-bulb first. Repeat until two successive wet-bulb readings are the same, indicating that the wet-bulb temperature has reached its lowest point. If the wet-bulb temperature rises between successive readings, remoisten the wick and reventilate. Accurate readings are especially important at low temperatures, where a given wet-bulb depression has a greater affect on accuracy of humidity computations.

To obtain accurate readings, the air passing over the psychrometer bulbs must have a speed of at least 15 feet per second. This can be attained by spinning the sling psychrometer at a rate of approximately two revolutions per second. This is best accomplished in a shady spot where there are not obstructions within radius of the whirling sling. Face into the wind. Whirl the psychrometer as far in front of the body as possible.

(4) Wind. The wind velocity is measured with a standard USWB Robinson 3-Cup Totalizing Anemometer. The difference in the readings of the totalizer on this instrument from one observation to the next equals the total miles of wind that has passed the station during the observation period. The general wind direction over the observation period should also be recorded.

(5) General Conditions. Sky conditions should be reported in 10ths of sky coverage from 1, completely obscure, to 0, indicating clear. This information is useful in estimating the amount of incoming radiation. Visibility should be recorded in miles and 10ths of miles. Fog is the phenomenon that most frequently restricts visibility. The following is a description of the fog conditions which might occur and which should be made a matter of record.

In contrast to drizzle of large ice crystals, fog droplets and ice fog particles have no visible downward motion. They differ from cloud in that their bases are at the surface, and the base of cloud is above surface. Essentially, fog is a cloud of small water droplets suspended in the air that reduces the horizontal visibility at the earth's surface. Most fog is distinguished from haze primarily by its dampness and gray color, in contrast to the somewhat more opalescent (milky white), or blue, appearance of haze. This distinction is often difficult to make in borderline cases. Although fog seldom forms when the difference between the air temperature and the dew-point temperature is greater than 4.0F°, it should be reported when observed, regardless of the amount of this difference. At temperatures below freezing the difference may exceed 4.0F°.

Fog may produce rime or glaze on cold exposed objects, and may transform rapidly into ice fog at low temperatures, usually below -20°F. A suspension of numerous minute ice crystals forms in the air and reduces the horizontal visibility at the earth's surface.

Ice fog does not produce rime or glaze on cold exposed objects.* When ice fog is observed, temperatures are usually at or below -20°F. At relatively high ice fog temperatures (-36°F to -20°F) the fog usually consists predominately of prism-like ice crystals, often evidenced by optical effects typical of ice prisms such as scintillation in sunlight or other light beams, halo phenomena, luminous vertical columns (pillars) over lights, etc. It may sometimes appear gray in color, especially at lower ice-fog temperatures. At temperatures below -36°F the ice crystals (or other particles) are usually smaller and lack clear-cut prism-like

*This is generally true for all of Alaska. It is not always true for parts of Antarctica.

characteristics; these particles are described as being nearly spherical with rudimentary crystalline faces. Ice fog intensity usually decreases as the proportion of prism-like ice crystals increases. In concentrations which barely restrict visibility, the crystals are also called "diamond dust". In ice fog the difference between the temperature and the dew point may approach 8F° or more.

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APPENDIX B

## The Determination of Snow Cover Properties

### 1. Introduction

Knowledge of the mechanical properties of the snow cover is significant to military operations in many ways. In no way, however, is its significance more vital than as a measure of the performance characteristics of various vehicles during off-road or cross-country mobility tests (Abele, 1967). To evaluate a vehicle's performance in such tests, it is necessary to obtain sufficient data on the terrain characteristics and snow cover of the test course so that comparisons can be made of 1) a particular vehicle's performance in various types of snow cover and terrain conditions (a terrain trafficability* comparison) and/or 2) the performance of various vehicles in a particular snow cover and terrain condition (a vehicle mobility** comparison).

Data on snow characteristics is also needed to evaluate vehicle performance on hard packed snow on pavements, as well as over-snow troop movements, on foot or on skis. Studies on snow cover properties and their relationship to climatic conditions have been discussed by Benson (1967), Bilello (1957, 1967) and Bilello et al. (1967).

### 2. Tests on Snow Cover and Terrain

The relationships between the predominate characteristics of terrain, snow cover, and vehicle design are shown schematically as functions of mobility in Figure 1B. The most significant snow cover and terrain characteristics are shown in the heavy boxes; their influences on vehicle mobility are indicated by heavy arrows.

Density. All the various snow strength indices (unconfined, tensile, shear, hardness, elastic modulus, etc.) are highly dependent on density. With reference to snow, density probably has a more tangible meaning than any other property since it represents a means for comparison with ice or with water.

Obtaining of a snow density profile requires digging a snow pit to expose a vertical face through the seasonal snow cover. The snow cover will usually consist of several identifiable layers which may be the products of storm precipitation or intensive drifting. Between layers there generally are areas of crust or ice lenses due to wind action or melting from solar radiation and/or above-freezing temperatures and subsequent refreezing. Each primary layer may include several secondary layers which

*Trafficability - the capability of the ground surface to support a vehicle or vehicular traffic.

**Mobility - the capability of a vehicle to travel over the ground surface.



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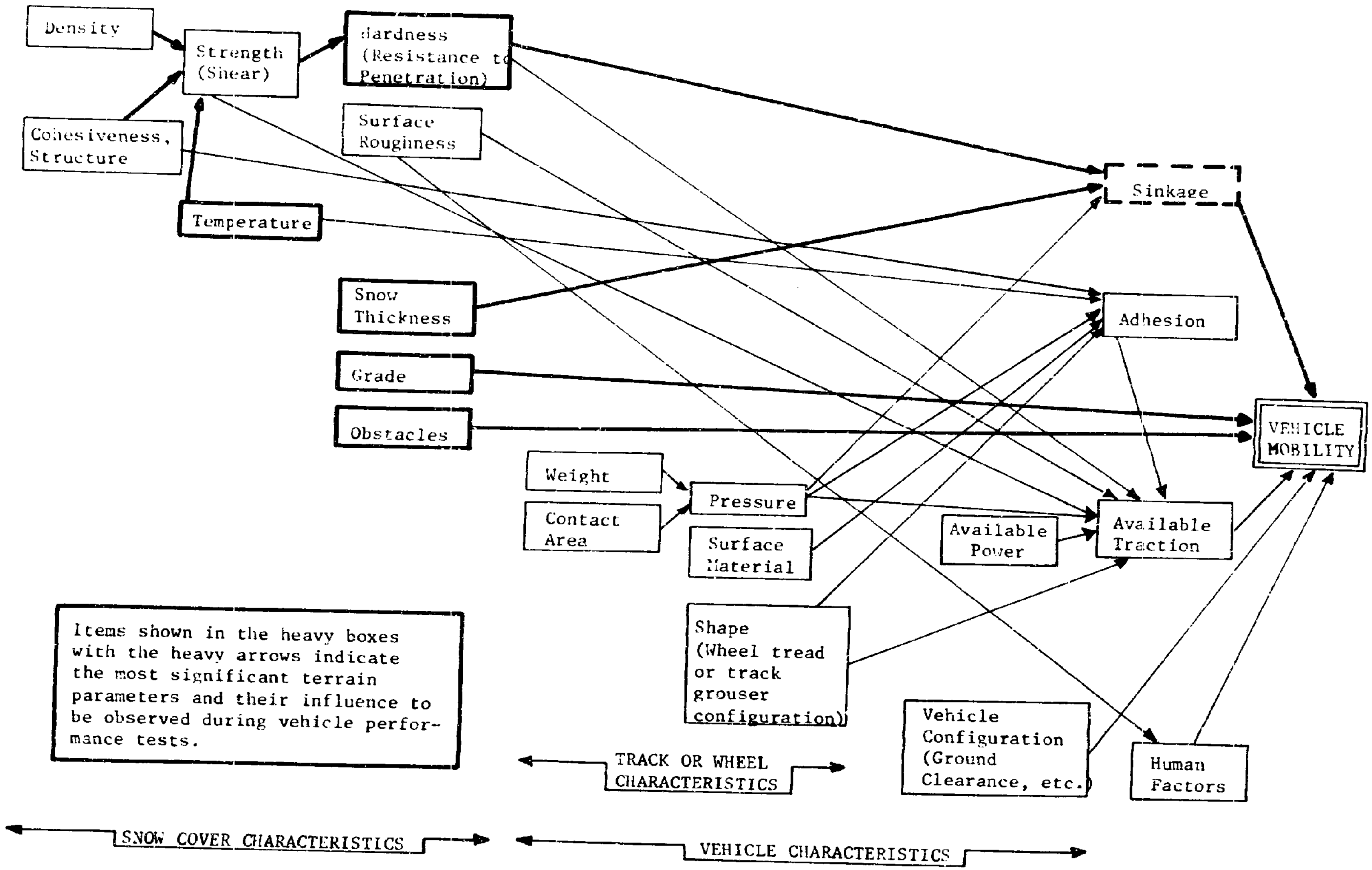



PREDOMINANT TERRAIN AND VEHICLE PARAMETERS AND THE MANNER OF THEIR INFLUENCE ON VEHICLE MOBILITY ON A SNOW COVERED TERRAIN

**Figure 1B**

sometimes make identification of the primary layer difficult. Nevertheless, if at all possible, the profile should be divided into horizons representing periods of major storm precipitation or periods of high winds and drifting. Density measurements of these major layers will usually be sufficient for describing the overall density characteristics of the profile.

The snow observation kit (Figure 2B) contains snow sample tubes, 500 $cm^3$ volume, with rubber caps. The snow tubes are inserted horizontally into the center of each major snow layer (see Figure 3B) and removed carefully by digging them out with the metal cutoff plate included in the kit. The excess snow is removed and rubber caps are placed on both ends of the tube. The snow-filled tube is then weighed on the scale included in the kit, and the density ($g/gm^3$) is computed by dividing the net weight (grams) of snow (gross weight minus tare weight) by 500 (the volume of snow). (It is actually more convenient to multiply the snow weight by two and to move the decimal point three places to the left.)

While taking the density observations, it is common practice to record the snow profile characteristics pertaining to snow <u>structure</u> and <u>cohesiveness</u>, which affect snow strength independently of density. A typical profile description is shown in Figure 3B. The data are recorded on cards (provided with the snow kit) as shown in Figure 4B. Temperature measurements every 15 or 20 cm (or smaller intervals in deep snow) are sufficient.

Although density and snow structure have a significant effect on the strength properties or the load supporting capacity of snow, they are not reliable snow strength indices. A change in temperature has a significant influence on snow strength, but very little effect on density. The effect of temperature on snow structure is largely dependent on time lapse. Therefore, when evaluating or predicting snow strength from density and structure, existing temperature, time or age of the snow, and the temperature fluctuations to which the snow cover has been subjected, have to be considered. These, of course, are difficult to evaluate. For example, it is possible to have a relatively strong snow layer of low density as contrasted with a layer of higher density but lower strength, the result of weaker structure or higher temperature. However, other characteristics being equal, strength increases with an increase in density, and decreases with an increase in temperature. It would be highly desirable if a snow property index could be developed capable of use as a strength or supporting capacity measure irrespective of structure, density, temperature, etc. This would reduce chances of making erroneous assessments of the strength factor. The relationships of the various snow characteristics have been discussed in more detail by Abele (1963 and 1968), Kovacs (1967), and Mellor (1964).

# SNOW OBSERVATION KIT

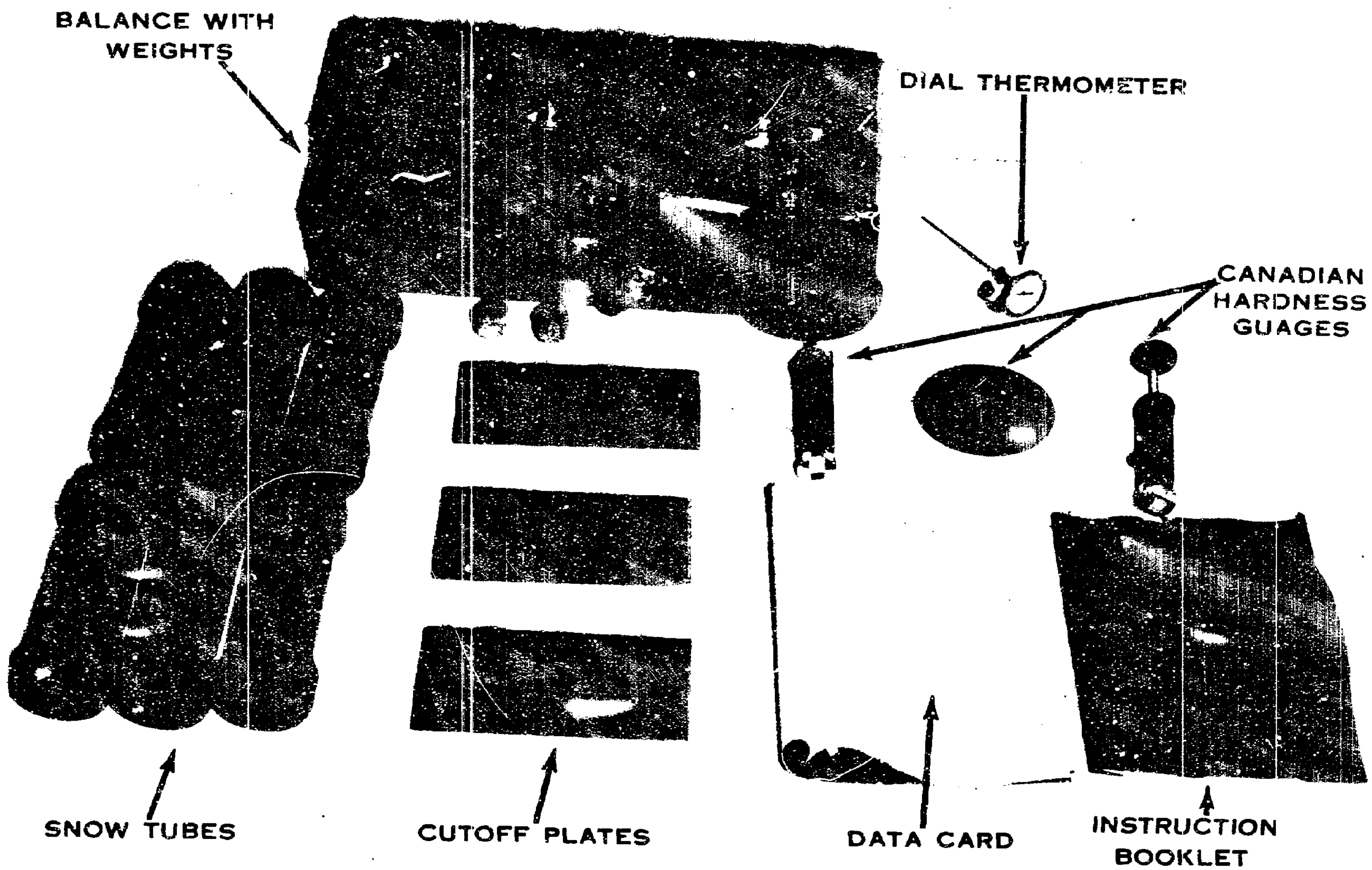
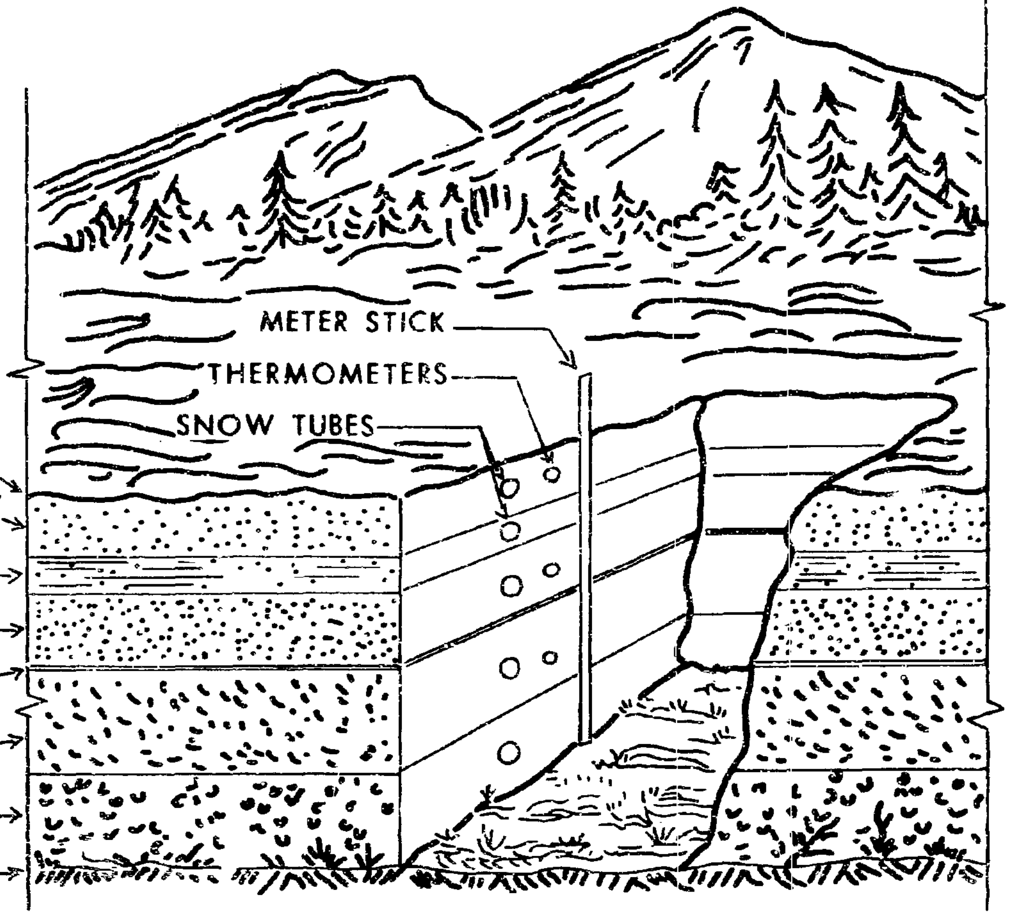



Figure 2B

| DEPTH(CM) | PROFILE DESCRIPTION |
|---|---|
| | SURFACE, GENTLY UNDULATING |
| 0-6 | SOFT, FLUFFY, DRY, NEW SNOW |
| 6-10 | WIND SLAB, HARD SNOW |
| 10-18 | COHESIVE, FINE GRAINED |
| 18 | ICE CRUST, 2-4mm THICK |
| 18-31 | COHESIVE, SOFT, COARSE |
| 31-43 | DEPTH HOAR, COHESIONLESS |
| 43 | GROUND, GRASS COVERED |




CROSS SECTION OF SNOW PIT

Figure 3B

## SNOW PROFILE

Location Butch Lake Sfc. Desc. Gently undulating Air Temp -6°C

Date 21 Feb 68 Time 9 AM Observer G.A.

| Depth (cm) | Temp. (°C) | Snow tube No. | Tare | Gross | Snow wt. | Density | Remarks |
|---|---|---|---|---|---|---|---|
| 0-6 | -7 | 1 | 301 | 391 | 90 | .18 | New snow, soft, dry |
| 6-10 | | 2 | 298 | 518 | 220 | .44 | Wind slab, hard |
| 10-18 | -8 | 3 | 302 | 477 | 175 | .35 | Cohesive, fine |
| 18 | | - | - | - | - | | Ice crust, 2-4 mm |
| 18-31 | -10 | 4 | 291 | 446 | 155 | .31 | Cohesive, coarse |
| 31-43 | | 5 | 290 | 420 | 130 | .26 | Cohesionless, coarse |
| 43 | | - | - | (Ground) | | - | (Grass covered) |
| | | | | | | | |
| | | | | | | | |

SNOW PROFILE DATA CARD
Figure 4B

Shear strength, as well as unconfined compressive strength, is a fairly reliable index for estimating the load supporting capacity of snow. However, these tests involve time-consuming sample preparations and are inconvenient because of the amount of equipment required. Other strength tests such as the California Bearing Ratio and plate bearing tests, which are very good indicators of terrain supporting strength, require even more time and heavier equipment.

For reasons of convenience therefore, cone penetrometers of various types have been developed as replacements for the bulky equipment mentioned. These have been used quite successfully in snow for predicting the trafficability of a snow surface.

Hardness. One of the most significant properties of a snow cover is its "resistance to penetration" (hardness). This is the property which is directly related to sinkage rates of vehicles and other applied loads. The sinkage rate for a particular vehicle in a given situation has definite and predictable effects on the vehicle's mobility.

Within certain limits, the hardness of snow also influences the traction of a vehicle. Compacted snow, such as characterizes most highways, is occasionally so hard that track grousers cannot penetrate it, resulting in insufficient traction particularly on grades.

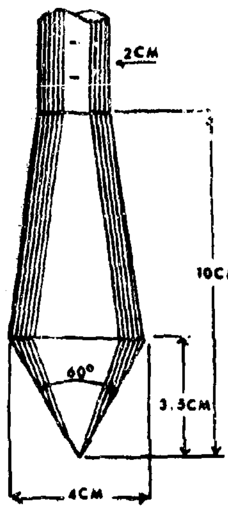
A cone penetrometer, such as the Rammsonde, is particularly useful in evaluating the supporting capacity of snow. The instrument is very convenient, easy to operate, and provides the means for quickly obtaining a hardness profile of the snow cover.

The standard Rammsonde hardness instrument consists of a hollow aluminum shaft with a 60° conical tip, a guide rod, and a drop hammer. The guide rod, inserted into the top of the shaft, guides the drop hammer. The hammer is raised by hand to a prescribed height on the guide rod (as indicated by the settings on the cm scale), and then dropped freely (Figure 5B).

Readings can be obtained in two ways. Several hammer drops (or blows) may be required to obtain a certain penetration if the snow is unusually hard. Any convenient penetration increment (for instance 5 cm) may be selected as a standard for comparison. If the snow is soft and layered, however, penetration varies with each drop. In this situation, the total penetration caused by a given number of drops is customarily recorded, but, occasionally, the record of each drop may be required. The depth of penetration is read from the cm scale on the shaft.

The standard 60° penetrometer cone (Fig. 5B), with a diameter of 4 cm is frequently too small (too slim) to be used in a natural snow cover, except in hard-packed drifts. Consequently, the 120°, 10 cm diameter cone is used more extensively (Figure 6B).

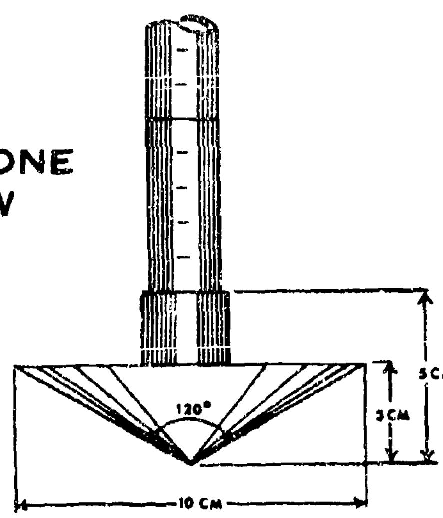
Figure 5B




RAMMSONDE PENETROMETER
WITH STANDARD CONE

Figure 6B

MODIFIED RAMMSONDE CONE
FOR USE IN SOFT SNOW



Three hammers, 3 kg, 1 kg, and 0.5 kg, are provided in the Rammsonde kit. The selection of hammer weight, drop height and cone type, should be such that the resulting penetration from each hammer drop is between one and five cm. The Rammsonde ("ram") hardness number is computed from the following equation:

$$R = \frac{Whn}{s} + W + Q$$

where:

R= ram hardness number

W= weight of hammer (kg)

h= height of drop (cm)

n= number of blows

s= penetration after n drops (cm)

Q= weight of penetrometer (kg)

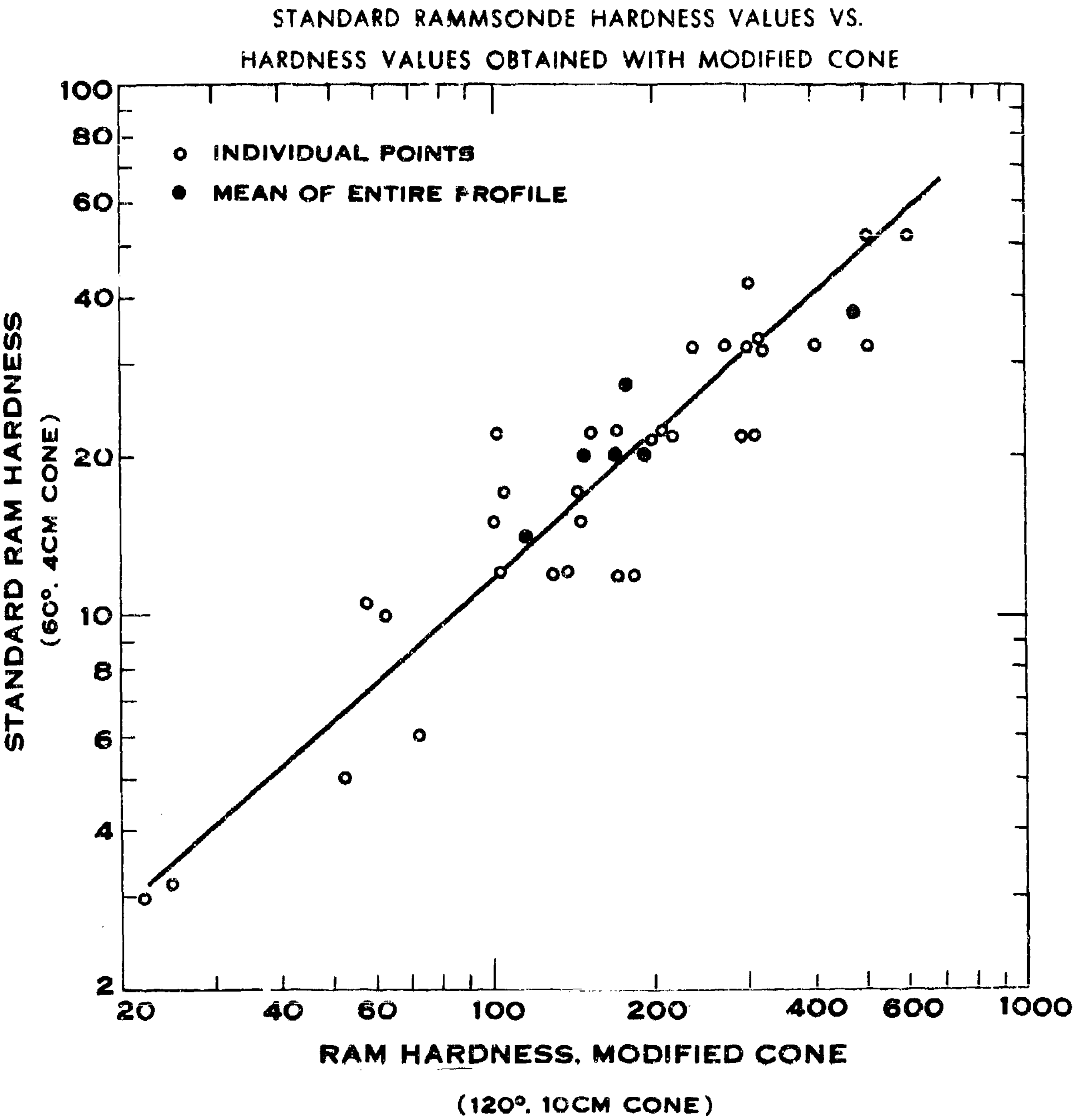
The above expression does not take into consideration the cone shape. Therefore, a tentative experimental relationship has been established between the standard ram hardness numbers obtained with the standard 60°, 4-cm cone and the hardness numbers obtained with the 120°, 10cm cone using the above equation (Figure 7B).

It should be noted that the penetrometer cone has to penetrate to its maximum width (3.5 cm from the tip for the standard cone and 3 cm for the large cone) before valid hardness readings can be observed.

The ram penetrometer test data are recorded on data cards (provided in the Rammsonde kit) as shown in Figure 8B. The use of the Rammsonde cone penetrometer has been discussed in various reports (Abele, 1963; Niedringhaus, 1965; Waterhouse, 1966).

The ram penetrometer cannot be used in very hard compacted snow such as that characterizing winter roads after considerable traffic. The hardness of this type of snow can be determined with a hand penetrometer, such as the Canadian Hardness Gauge or the Soil Penetrometer (Figure 2B). Hardness readings with the Soil Penetrometer are obtained by pushing the probe into the snow to a depth of 6 mm (¼ in., indicated by a red line) and observing the position of the sliding red collar on the graduated shaft (disregard the strength units, etched beside the scale, which pertain to soil values and have no significance in this case) . The penetrometer readings indicate the pressure applied, as shown in Figure 9B.

The Canadian Hardness Gauge can also be used for this purpose, but the design of the Soil Penetrometer permits a more conveneient use and reading of the instrument.


STANDARD RAMMSONDE HARDNESS VALUES VS.
HARDNESS VALUES OBTAINED WITH MODIFIED CONE
INDIVIDUAL POINTS
MEAN OF ENTIRE PROFILE
STANDARD RAM HARDNESS
(60°. 4CM CONE)
100
80
60
40
20
10
8
6
4
2
20
40
60
100
200
400
600
1000
RAM HARDNESS, MODIFIED CONE
(120°. 10CM CONE)
Figure 7B

## RAMMSONDE HARDNESS No. 1

Location Tank range Test Position

Surface Descr. Drifts to 10 cm high

Age Hard. — Snow T -5°C Air T -7°C

Date 19 Feb 68 Time 0945 Observer GA

Remarks Std. cone

Hardness No. = $R = \frac{Whn}{x} + (W + qQ)$

W = Wt of hammer (kg)
q = No. of tube lengths
Q = Wt. of one tube (kg)
x = Penetration resulting from n blows
h = Height of fall (cm)
n = No. of blows
d = Depth of cone

| W | h | n | d | x | $\frac{Whn}{x}$ | W+qQ | R | |
|---|---|---|---|---|---|---|---|---|
| 1/2 | 20 | 0 | 4 | 4 | – | 1.5 | – | |
| " | " | 1 | 7 | 3 | 3.3 | " | 4.8 | |
| " | " | 1 | 11 | 4 | 2.5 | " | 4 | |
| " | " | 4 | 13 | 2 | 20 | " | 21.5 | |
| " | " | 3 | 14 | 1 | 30 | " | 31.5 | |
| " | " | 5 | 17 | 3 | 17 | " | 18.5 | |
| " | " | 2 | 20 | 3 | 6.7 | " | 8.2 | |
| " | " | 2 | 25 | 5 | 4 | " | 5.5 | |
| " | " | 3 | 30 | 5 | 6 | " | 7.5 | |
| " | " | 1 | 36 | 6 | 1.7 | " | 3.2 | |
| " | " | 1 | 43 | 7 | 1.4 | " | 2.9 | |
| | | | 45 | (Ground) | | | | |

Hardness values not valid until cone has fully penetrated into snow (d > 3.5 cm for std. cone; d > 3 cm for large cone)

## RAMMSONDE HARDNESS No. 2

Location Butch Lake Test Position

Surface Descr. Undulating, 3 to 6 cm high

Age Hard. — Snow T -9°C Air T -8°C

Date 19 Feb 68 Time 1300 Observer GA

Remarks Modified (large) cone

Hardness No. = $R = \frac{Whn}{x} + (W + qQ)$

W = Wt. of hammer (kg)
q = No. of tube lengths
Q = Wt. of one tube (kg)
x = Penetration resulting from n blows
h = Height of fall (cm)
n = No. of blows
d = Depth of cone

| W | h | n | d | x | $\frac{Whn}{x}$ | W+qQ | (R) | R |
|---|---|---|---|---|---|---|---|---|
| 1 | 20 | 1 | 3 | 3 | | 2 | – | – |
| " | " | 2 | 5 | 2 | 20 | " | 22 | 3 |
| " | " | 8 | 10 | 5 | 32 | " | 34 | 4.5 |
| " | " | 10 | 15 | " | 40 | " | 42 | 5.5 |
| " | " | 13 | 20 | " | 52 | " | 54 | 7 |
| " | 30 | 8 | 25 | " | 48 | " | 50 | 6 |
| " | " | 9 | 30 | " | 54 | " | 56 | 7 |
| " | " | 7 | 35 | " | 42 | " | 44 | 5.5 |
| " | " | 10 | 40 | " | 60 | " | 62 | 7.5 |
| | | | 43 | (Ground) | | | | |

Computed values from above formula

Actual hardness values, from Fig. 5

RAM HARDNESS DATA CARDS

Figure 8B

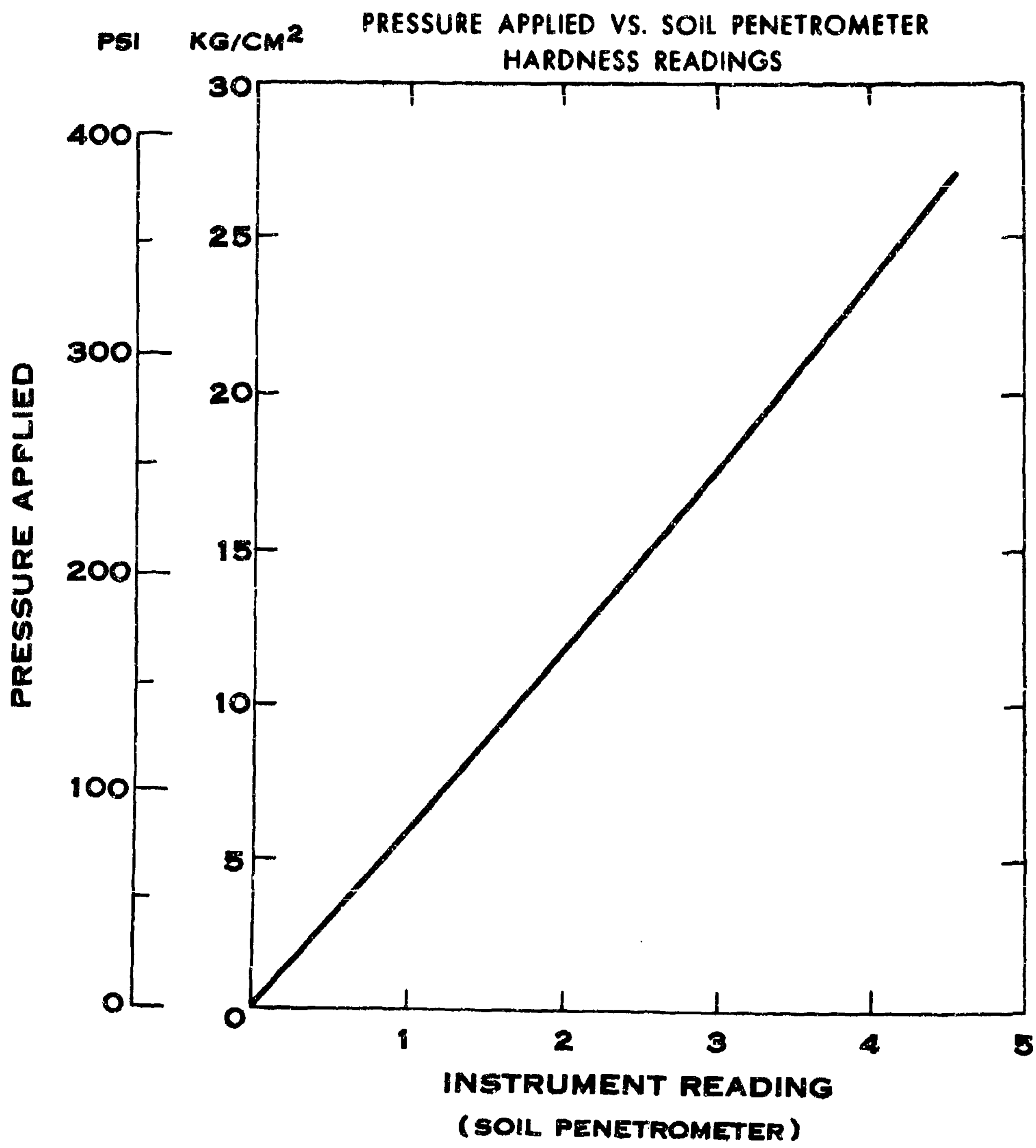

PSI
KG/CM²
PRESSURE APPLIED VS. SOIL PENETROMETER HARDNESS READINGS
30
25
20
15
10
5
0
400
300
200
100
0
PRESSURE APPLIED
1
2
3
4
5
INSTRUMENT READING
(SOIL PENETROMETER)

Figure 9B

The snow hardness range for which either of the two hand penetrometers can be used is limited to penetration pressures of approximately 56 kg/cm$^2$ (800 psi).

Snow thickness. Snow thickness is a simple but important measurement, since the rate of vehicle sinkage, within certain limits, is determined by it. Its influence on vehicle mobility is greatest when the snow cover is just beginning to form, decreasing thereafter as the snow thickness increases. For example, a change from 20 cm to 40 cm thickness is very significant as far as vehicle performance is concerned, but it is practically immaterial whether the snow is two meters or four meters deep.

Grade. This parameter can be expressed either in terms of percent (which is more common and, therefore, preferred) or in degrees.

Obstacles. Any minor but sudden change in the terrain configuration relative to the horizontal, such as mounds, banks, drifts, ditches, depressions, trees and shrubs are considered obstacles in contrast with 1) snow surface features, or irregularities resulting from wind erosion; and 2) major terrain features such as hills.

Since it is not yet possible to apply a rational classification scheme to such obstacles, their identification rests heavily on descriptive characterization of the obstacles in question, such as the approximate dimensions of ditches and mounds, the size and spacing of trees, and the slope and height of river banks.

Some indication of surface roughness, which may be defined as the irregularities of the snow surface as shaped by wind erosion and deposition, is desirable if the surface is sufficiently hard to affect vehicle ride comfort, or if ease or personnel movement on foot or on skis must be assessed. Surface roughness is also of critical concern to aircraft landings and take- offs. The properties of snow cover so far discussed relate almost entirely to problems of vehicle mobility. There may be occasions, however, when other snow properties may be of significance (USA CRREL, 1962). Snow particle size, for example, is of significance to visibility when blowing snow becomes a problem due to the number and size of the particles in the air.

The snow observation kit contains graduated plates for measuring grain size. Since the concentric circles etched on the plate are one millimeter apart, size of fine particles has to be estimated with a magnifying glass.

Temperature. Since temperature information is useful in many different situations and because the observations require so little time and effort, temperature data should be obtained during all tests. During vehicle mobility tests, temperature of the snow surface should be observed, as well as the temperature of the air at a height equal to the topmost level of the vehicle. Some record of day time versus night time temperatures also

may prove useful, since the snow cover, in certain situations, may become sufficiently trafficable at night to sustain mobility tests, though too weak during the warmer days to support vehicular traffic.

The snow kit is provided with several dial-type, bimetallic thermometers. In hard snow, the probe (see Figure 2B) can be used to make a hole into which the thermometer stem is inserted.

Summary

The most significant snow cover characteristics to be observed for purposes of trafficability assessment are:

1) Resistance to penetration or snow hardness.

2) Snow thickness.

3) Terrain grade.

4) Description of obstacles.

5) Snow temperature.

A density profile(s) of the snow cover in the test area is of sufficient general value to take the time to acquire. Usually, a description of the nature and composition of the snow cover profile (as well as that of the snow surface) can be obtained with little additional effort.

The snow observation kit and the Rammsonde kit, both available from USA TSC, contain all the instruments required for performing the necessary snow cover measurements.

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## APPENDIX C

### The Test Facilities at Ft. Greely

The locations and sizes of the ranges and other testing facilities at Ft. Greely are shown on the frontispiece. The U.S. Army Test Center has direct or indirect interests in about one million acres, or 1,560 square miles of real estate in northern Alaska within the drainage basin of the Tanana River. At Ft. Greely the test facilities total about 560,000 acres which include firing areas for artillery, tanks, mortar and small arms, a 600-acre air-drop zone, vehicle courses and a chemical test area.

Test Center facilities include: three multipurpose sites; a network of vehicle test courses; improved terrain area; support facilities including an aircraft hangar; track vehicle maintenance shops capable of accomplishing up to and including general support maintenance; an effective supply complex; and highly developed photographic, graphic arts and allied trades facilities.

#### Ranges

Each range facility has independent access roads, power sources, data collecting equipment, bunkers and firing points that are consistent in quantity and variety with usage and purpose for which constructed. Ranges, where feasible, are provided with lighting for testing during hours of darkness, when most favorable testing temperature generally occur. The airspace over each range is restricted to unlimited altitudes at all seasons. Entry into the restricted airspace is controlled through the Federal Aviation Agency Station, Big Delta.

#### Beales Range

This range consists of two firing pads for testing of artillery weapons. Firing may be conducted to a range of 50,000 meters from one firing pad which consists of eight surveyed firing positions and a cleared fire land 2,000 meters long by 500 meters wide. It is used principally to conduct service test firing. The other firing pad consists of three firing positions oriented toward three separate impact areas and is used primarily for engineering test firing and service test firing of long-range artillery weapons. About 300 acres of land have been cleared for this firing pad. Observation posts, each including a surveyed instrument position, have been established every 1,500 meters throughout the impact area.

#### Tank Range

The range has six concrete firing pads, seven illuminated stationary target areas varying in distance from 500 to 2,000 meters and moving targets at 1,000 and 2,000 meter distances. The complex is used primarily for test firing of tanks and as a center for cross-country vehicle testing and vehicle cold soaking.



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Field Firing Range

This range consists of a cleared area of 103 acres and is used principally for combat firing tests of small arms.

Mortar Range

Originally constructed as a multipurpose test site, this 20-acre site is now used primarily for mortar firing with occasional testing of artillery and antiaircraft weapons, flame-throwers and miscellaneous equipment.

Air Defense Range

This range is remotely located to minimize drone interference with other aircraft and weapons.

Small Arms Complex

This complex is used for testing various infantry support weapons. Its principle elements are:

| | |
|---|---|
| Sawmill Site: | A 17-acre cleared area used for testing grenades, mines, and short range direct fire weapons. |
| Known Distance Site: | A cleared area of 15.2 acres with ten rifle firing positions each with measured target distances to 1,100 meters. |
| Recoilless Site: | Constructed to test various types of longer range direct fire weapons. Firing platforms and target berms are located to permit firing at all ranges between 100 and 2,000 meters. |
| TOW Site: | Specifically constructed to test the new TOW weapons. |

Multipurpose Test Sites

Since tests are conducted on all items of Army equipment and materiel, several test sites have been prepared for a variety of final uses. Other areas, as yet undeveloped, have been set aside for additional special and multipurpose uses. Sites developed are:

Bolio Lake Test Site

This facility is principally devoted to nonfiring test activities. It includes a fenced-in building complex of 4.6 acres where clothing, individual equipment, rations, tentage and cold soak tests are conducted. Within and about the complex are a number of driving courses and ski trails where cross-country ski and vehicle tests are conducted.

Drop Zone

Air delivery tests including techniques development tests, drop tests of men and equipment, and cargo retrieval tests are conducted at this site. To date [illegible]16 acres of land have been cleared within the site for testing purposes.

Gerstle River Test Site

This site is used to conduct tests of chemical equipment and materiel, including incendiaries and demolitions. The 19,000-acre area includes a gas chamber, toxic agent yard and four cleared grid stages.